Measurement of the amplitude and phase modulation of a liquid crystal spatial light modulator

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In this paper an alternative and simple technique to measure the complex transmittance of a liquid crystal spatial light modulator (LC-SLM) is presented. By means of this technique the user can measure the amplitude and phase modulation of any LC-SLM through a simple interferometric setup. Particularly, optical characterization of specimen Holoeye LC2002 is carried out and its amplitude and phase curves are obtained.

Keywords: Liquid crystal spatial light modulator; Complex transmittance measurement, Optical characterization

1. Introduction

Liquid crystal spatial light modulators LC-SLM have found a wide range of applications in optical processing, adaptive optics and holography, among others. Usually LC-SLMs are inserted between two polarizers in order to modify its complex transmittance; mathematically, the transmission function is written as

$$T(\phi_D, \phi, \beta; \Psi_1, \Psi_2) = J_\phi(\Psi_2)J_{\text{LCD}}(\phi_D, \beta)J_\phi(\Psi_1),$$

where $J_\phi$ and $J_{\text{LCD}}$ are the Jones matrices of polarizer and LC-SLM, respectively. The parameters in Eq. (1) have the following meaning: $\phi_D$ is the azimuth angle of LC-SLM front director; $\phi$ is the twist angle; $\beta$ is the birefringence; $\Psi_1$ and $\Psi_2$ are the azimuth angles of extraordinary polarizer axes.

In our approach, transmission of LC-SLM between two polarizers is function of polarizer’s angles $\Psi_1$ and $\Psi_2$, gray level $U_{\text{mod}}$ of video signal and finally, in the case of specimen LC2002 parameters bright $B$ and contrast $C$, all modified by the user. Parameters $U_{\text{mod}}, B$ and $C$ are related to electrical signals controlling the LC-SLM; $U_{\text{mod}}$ is an AC voltage applied to each individual pixel in the LC-SLM, $B$ is a constant DC voltage applied to all pixels and $C$ determines the maximum AC voltage magnitude that can be applied to LC-SLM pixels.

Writing Eq. (1) in its complex form

$$T(x) = |T(x)| \exp(i\delta(x)),$$

where $|T(x)|$ and $\delta(x)$ are the amplitude transmittance and phase transmittance; respectively, we define the amplitude modulation mode and phase modulation mode of LC-SLM as

![Figure 1. Young’s interferometer: S-screen with two apertures, LC-SLM, L-lens, D-detector.](image-url)
Figure 2. LC-SLM characterization system. 1)Laser, 2)$\lambda/4$ plate, 3)Ronchi grating, 4)Zeroth’s order obstacle, 5)Diaphragm, 6)Lens, 7)Polarizer, 8)LC-SLM, 9)Second polarizer (analyser), 10)Microscope objective, 11)CCD or photodiode, 12)PC.

Figure 3. Ensemble images corresponding to amplitude (left) and phase modulation (right) of LC-SLM LC2002.

Figure 4. Amplitude modulation of the LC2002 as a function of a) contrast, b) bright.

$T(U_{\text{mod}}, \Psi_1, \Psi_2, B, C) = K_i U_{\text{mod}}$,  
$\delta(U_{\text{mod}}, \Psi_1, \Psi_2, B, C) = \text{const}$,  
and

$T(U_{\text{mod}}, \Psi_1, \Psi_2, B, C) = \text{const}$,  
$\delta(U_{\text{mod}}, \Psi_1, \Psi_2, B, C) = K_i U_{\text{mod}}$,  
respectively. In order to measure the behavior of $\|T\|$ and $\delta$, the Young’s interferometer setup is used. Introducing into the LC-SLM the modulation signal

$U_{\text{mod}}(x) = \begin{cases} 
  u_1, & x < 0 \\
  u_2, & x > 0 
\end{cases}$

the intensity of the interference pattern in Fig. 1 has the form

$I(x) = E_0^2 |F(u_1)|^2 + E_0^2 |F(u_2)|^2 + 2E_0^2 |F(u_1)F(u_2)| \cos \left( \frac{2\pi}{\lambda f} x - \delta(u_1) + \delta(u_2) \right)$,  

where

$E_0$ is the amplitude of the illumination field,  
$x_0$ is the separation of screen’s apertures,  
$f$ is the focal distance of the lens,  
$\lambda$ is the wavelength of the source,  
$x$ is the longitudinal displacement of the fringe pattern.

Eq. (6) carries information about the amplitudes and phases of gray levels $u_1$ and $u_2$. In order to extract amplitude and phase information, we use the so called fringe’s visibility

$V = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}$,  

substituting in (7) values $\text{min}$ and $\text{max}$ of Eq. (6) visibility is expressed as

$V = 2 \frac{|T(u_1)|^2 |T(u_2)|^2}{|T(u_1)|^2 + |T(u_2)|^2}$.  

Fixing to black (gray level 255) one of the signals of Eq. (5), while the other half of LC-SLM’s is white (gray level 0), we find that amplitude modulation and phase modulation fulfil the conditions
Equations (9.2) and (10.2) indicate that amplitude modulation occurs when the fringe pattern looks most blurred and phase modulation occurs when contrast is strongest.

The first step in the optical characterization of the LC-SLM is to find the values of polarizer’s angles $\Psi_1$ and $\Psi_2$ that make visibility of the interference pattern minimum and maximum. Once the polarizer’s angles for each kind of modulation are found, the next step is to measure the amplitude and phase curves of the LC-SLM as a function of gray level. This is done varying the gray level of one half of the video signal sent to the LC-SLM while the other remains fixed to black.

3. Experimental setup

The experimental setup to measure amplitude and phase modulation of the LC-SLM between two polarizers is shown in Fig. 2. In the figure, $\lambda/4$ plate makes the incoming light circular to avoid cancellation by polarizers, then a Ronchi grating decomposes the light into several orders and the obstacle and diaphragm take the first two. Finally a lens directs the beams through the LC-SLM between two polarizers and make them to interfere, forming pattern of Eq. (6). In the diagram, part 10 expands the interference pattern, 11 measures amplitude or phase and 12 sends video signal $U_{\text{mod}}$ to the LC-SLM.

Several measurements were made to the LC-SLM LC2002 Holoeye with a He-Ne laser $\lambda=633$nm. Angles $\Psi_1$ and $\Psi_2$ where amplitude modulation occurred were $(90^\circ, -2.5^\circ)$ and those for phase modulation were $(45^\circ, -90^\circ)$.

Typical images of the interference pattern are shown in Fig. 3. In the image, it can be seen that conditions (9.2) and (10.2) are satisfied in each case; i.e., low and high visibility.

Curves of amplitude and phase modulation modes as function of gray level and different values of bright $B$ and contrast $C$ are shown in figures 4, 5 and 6. The curves were obtained taking 10 increments in the 0-255 gray level scale. Amplitude mode curves were measured with a photo detector in the whole pattern. Due to the poor visibility of this mode, phase coupled curves weren’t calculated because it was very hard to measure phase shifts precisely. In Fig. 4 it can be observed that intensity of transmitted light in amplitude modulation mode behaves linearly at low contrast levels given a fixed bright value. This can be explained in the basis that liquid crystal molecules inside...
the LC-SLM are less disturbed when the magnitude of contrast voltage is reduced, thus avoiding nonlinearities in the amplitude of transmitted light.

Phase mode curves were obtained measuring the fringe pattern displacement counting pixel shift with a CCD; it is shown that LC2002 is able to reach 270º phase modulation. Coupled intensity in phase mode is more flat than intensity of amplitude mode, as expected.

The curves demonstrate that neither amplitude and phase modes of LC2002 increase linearly; nevertheless, the optical modulation introduced by the device is still useful. The data indicate that’s possible to access a set of curves simply varying the values of bright and contrast of the LC2002.

4. Conclusions

It was developed an optical technique that helps the user to find the amplitude and phase modulation modes of any LC-SLM model without necessity of knowing its internal parameters. The presented technique is based on simple measurements of the output intensity and pixel shift in a modified Young’s experiment.

Applying our technique, angles $\Psi_1$ and $\Psi_2$ where amplitude and phase modulation occurred in specimen LC2002 at $\lambda=633$nm were found. The results show LC2002 can achieve 270º phase modulation with a somewhat flat coupled intensity. Amplitude modulation by the other side, shows a linearly response at low contrast levels.

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References