Azimuthal polarization states for the optimization of a liquid crystal display Sony LCX038ARA in the pure-phase regime

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Abstract. A liquid crystal display is an optoelectronic device contains molecules in an intermediate state between solid and liquid. In this work are showed numerical and experimental results of the azimuthal polarization states, which are used to optimize the pure-phase modulation of a Sony LCX038ARA LCD liquid crystal display for a linear polarized light beam with wavelength 632.8nm.

1. Introduction
A liquid crystal display is an optoelectronic device containing molecules that are in the intermediate state between solid and liquid [1]. Due the unique properties of these devices have been widely used as spatial light modulators (SLMs) [2]. Most of SLMs are of the nematic type are known as Twisted Nematic Liquid Crystal Displays (TN-LCDs). The TN-LCDs are widely used in applications in communications [3], medicine [4] and holography [5].

To characterize the complete behaviour of a TN-LCD is necessary to know the phase modulation of the LCD with applied electric field between their pixelated electrodes with respect to optical visible radiation [6]. In this work, we show the numerical and experimental results to generate states of equal azimuth i.e. [7] polarization states that allow to optimize the pure phase modulation of a Sony LCX038ARA liquid crystal LCD for a linear polarized light beam with a wavelength of 633.8nm using a system composed of a polarizer and a quarter-wave plate.

2. Methodology
The azimuth angle α and ellipticity angles ε can be used to describe polarization states over the sphere Poincaré [8]. The azimuthal polarization states represent southern curves over the sphere Poincaré with equal azimuth angle and variable ellipticity [9]. These states are generate used the LCD sandwiched between a polarizer and a quarter-wave plate appropriately oriented them [10]. To find the optimal orientations of the polarizer and the quarter-wave plate within the optoelectronic system we have generated approximately states of equal azimuth for the 26 grey levels using the schematic setup shown in Figure 1.

In addition, we have used the results for the intrinsic parameters total twist angle (∅), angle of the molecular axis at the entrance face (Ψ_D) and maximum birefringence (β) of the TN-LCD with null applied voltage showed in the Table 1 with the purpose of find the rotor and retardation effect added on an arbitrary phase state [9].
Figure 1. Schema of experimental setup used for measuring the optimal orientations of the polarizer (P) and the quarter-wave plate (QWP) in the azimuthal polarization state using linear polarized light to illuminate the LCD.

Table 1. Intrinsic parameters of the TN-LCD [11].

| Parameter                  | Value   |
|----------------------------|---------|
| Twister angle (θ)          | +93.8°  |
| Angle of the molecular axis (ΨD) | -14.9°  |
| Birrefrence (β)            | 2.126 rad |

Using the experimental schema of Figure 1, it is possible obtain that the light transmitted by the optoelectronic system is given by [9]:

\[ T = \cos^2(\alpha_0 - \xi) \cos^2 \varepsilon_0 + \sin^2(\alpha_0 - \xi) \sin^2 \varepsilon_0, \]  

(1)

With,

\[ \xi = \alpha_0 \pm \frac{\pi}{4} \]  

(2)

The longitudinal coordinate over the Poincare sphere, \( \varepsilon_0 \), is the elliptic angle and \( \alpha_0 \) is the azimuth angle. Then, the output field can be writing as:

\[ E_{out} = \frac{1}{\sqrt{2}} \exp[j(\pm \varepsilon_0 + \delta)] \binom{1}{0} \]  

(3)

2.1. Determination of angle theta 1(\( \theta_1 \)) y theta 2(\( \theta_2 \))

To find the values of \( \theta_1 \) and \( \theta_2 \) that maintain constant the azimuth state for the 26 gray levels (\( g \)) we have used the least squares method with the purpose of determine numerically the angles of the polarizers and the quarter wave plate that minimized the standard deviation \( \sigma \), which is defined as:

\[ \sigma(\theta_1, \theta_2) = \sqrt{\frac{1}{n-1} \sum (\alpha_g - \bar{\alpha})^2} \]  

(4)

With the Stokes parameters given by [6],

\[ s_0 = 1 \]  

(5)

\[ s_1 = \cos(2\theta_2) \left( \cos^2 \delta_{eq} \cos[2(\theta_1 - \theta_2 - \phi_{eq})] + \sin^2 \delta_{eq} \cos[2(\theta_1 - \theta_2 - \phi)] + \sin(2\theta_2) \sin(2\delta_{eq}) \sin[2(\theta_1 - \theta_2 - \phi_{eq})] \right) \]  

(6)
\[ s_2 = \sin(2\theta_2) \left( \cos^2 \delta_{eq} \cos \left[ 2(\theta_1 - \theta_2 - \phi_{eq}) \right] + \sin^2 \delta_{eq} \cos [2(\theta_1 - \theta_2 - \phi)] + \cos(2\theta_2) \sin(2\delta_{eq}) \sin [2(\theta_1 - \theta_2 - \phi_{eq})] \right) \]  
\[ s_3 = -\sin^2 \delta_{eq} \sin [2(\theta_1 - \theta_2 - \phi)] + \cos^2 \delta_{eq} \sin [2(\theta_1 - \theta_2 - \phi_{eq})] \]  

(7)  

(8)  

Where \( \phi_{eq} \) and \( \delta_{eq} \) are experimental equivalent rotor and retardation, respectively. We have used the Nelder-Mead method to minimize equation (6). The schema of the Figure 2 show the points used for the Nelder-Mead method. With this method we have calculate the optimal polarization states that generate a light beam with constant azimuth.

\[ m = (a + b)/2 \]
\[ r = m + (m - c) \]
\[ e = m + 2(m - c) \]
\[ s_1 = (c + m)/2 \]
\[ s_2 = (m + r)/2 \]
\[ c_1 = (c + a)/2 \]
\[ c_2 = (r + a)/2 \]

Figure 2. Notation used in the Nelder-Mead method [8].

### 3. Results

The Table 2 shows the optimal orientations of the polarizer and quarter wave plate that generate an azimuthal polarization state in the optoelectronic system. In this Table we also have calculate the standard deviation for these angles.

| Parameter               | Value     |
|-------------------------|-----------|
| Angle Theta1 \( (\theta_1) \) | 78.18°    |
| Angle Theta2 \( (\theta_2) \) | 61.48°    |
| Minimum \( (\sigma) \)     | 4.44 rad  |

Using the numerical results of the Table 2, we have found that the azimuthal polarization state is obtained with the azimuth angle 17.31°. To corroborate the azimuth angle, we proceed to find the experimental value using the setup shown in left side of Figure 3. A random polarized light from a Helium-Neon laser (Spectra physics, Power 5mW) with wavelength 632.8nm in the transverse electromagnetic ground state mode TEM00 is filtered and collimated using the objective (O), the pinhole (PH) and the lens L1, respectively. The TN-LCD has been placed between two polarizers (P and P1) and an analyser (A). Finally, a power-meter (PM) is placed at the focal plane of the lens to detect efficiently intensity measurements of the TN-LCD. The experimental arrangement polarizers (P and P1), TN-LCD and an analyser (A), also includes one-quarter wave plates (QWP or \( \lambda/4 \)), which has been adjusted to 78.18° with the purpose to obtain an equal-azimuth state.

The right side of Figure 3 shows the experimental results for a series of 26 images of grey levels ranging from \( g=0 \) to \( g=255 \) in steps of 10 displayed on the TN-LCD. In this Figure we can observe that the behaviour of the Stokes parameters S1 versus S2 is lineal, i.e., this state may be used like an equal-azimuthal polarization state with experimental azimuth of 17.31° [12] (put value). The discrepancy of
the numerical and experimental result can be explained if we take into account that the quarter wave plate is the multiple order for 632.8nm.

![Image](image-url)

**Figure 3.** (a) Experimental schema used to find the azimuth angle. (b) Experimental results for the Stokes parameter S1 and S2.

4. Conclusions

It was found that a state of equal azimuth in the optoelectronic system can be obtained for the $\theta_1 = 78.18^\circ$ and the $\theta_1 = 61.48^\circ$ orientations in the polarizer P and the quarter wave plate, respect to the molecular axis of the TN-LCD. This result is a cornerstone for the characterization of the matrix in pure-phase mode.

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