Global characterization of a nematic liquid crystal display LCX038ARA using the retarder-rotor model in the modulation amplitude regime-coupled without applied voltage

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Abstract. This work shows experimental and theoretical results of the characterization of a nematic liquid-crystal spatial light modulator Sony model LCX038ARA for the parameters angle of molecular rotation, the birefringence and angle of the molecular axis, using the retarder-rotor model without electric field applied in the amplitude regime-coupled.

1. Introduction
Liquid crystal displays (LCDs), are electronic devices contains a material that has liquid/solid properties sandwiches between two transparent electrodes. The unique properties of the LCDs make them attractive for applications such as spatial light modulators (SLM), which are widely useful in single molecular imaging [1-2] and optical tweezers [3-4]. Most SLM are nematic type and its properties can be explained using optics, electronics and materials science. According to the particular helical structure of each nematic liquid-crystal spatial light modulator can find some slight differences for the parameters: molecular twist angle, birefringence and angle of the molecular axis in an equal model of nematic liquid-crystal spatial light modulator. The main characteristic of SLM nematic type is that molecules of each layer tend to be parallel but their positions are random. If the angular orientation increases as going in a direction from the first layer to the last layer, then the LCD is called Twisted Nematic Liquid Crystal Display (TNLCD) [5-7].

To describe the behavior of a TNLCD, it is necessary to know the value of the parameters: the $\Psi$ and the birefringence ($\beta$). The birefringence parameter ($\beta$) is defined as [8-10],

$$\beta = \pi n_e - n_0 d$$

Where $\lambda$ is the wavelength, $d$ is the thickness of the LCD layer, while $n_e$ and $n_0$ are the extraordinary and the ordinary indices of refraction, respectively.

In this work present the model by Soutar-Lu (retarder-rotor model) combined with the Stokes parameters in order to experimentally find the values of the parameters of the LCD without applied voltage.

2. Methodology
Soutar-Lu method can be used to characterize a SLM in the amplitude coupled mode, i.e. maximize intensity response and minimize the response phase of the LCD to find the values of the twister angle $\Psi$ , and the birefringence($\beta$).
Figure 1. (a)-(b) Diagrams of reference and angles involved in the Soutar&Lu technique. (b) Detailed diagram for the polarizer and analyzer angles. Source [11].

Figure 1 shows the experimental setup used in Soutar-Lu method. In this figure can observe that the LCD is sandwiching between two lineal polarizer with of purpose to obtain the intensity of the system (Polarizer-LCD-Polarizer) in two configurations, which the polarizers are cross and the polarizers are parallel [11,12]. Using the model based on the Jones matrix theory it possible to find the intensity of the optical system given by:

Parallel configuration:
\[ T_p = X \cos \emptyset + Z \sin \emptyset + Y \cos (2 \xi - \emptyset - 2 \Psi D) \]

Cross configuration:
\[ T_c = -X \sin \emptyset + Z \cos \emptyset + Y \sin (2 \xi - \emptyset - 2 \Psi D) \]

With:
\[ X = \cos \gamma \]
\[ Y = \left( \frac{\beta}{\gamma} \right) \sin \gamma \]
\[ Z = \left( \frac{\beta}{\gamma} \right) \sin \gamma \]
\[ \gamma = \sqrt{\beta^2 + \beta^2} \]

2.1. Determination of the twist angle (\( \emptyset \)) and the angle of the molecular axis of the TNLCD (\( \Psi D \))

With the Soutar-Lu method is possible to find the magnitude of the twist angle (\( \emptyset \)) and (\( \Psi D \)) director axis orientation To at the input surface of the TNLCD, however the signs of these parameters cannot be determined. The use of Stokes parameters is proposed to find the sign of \( \emptyset \) and \( \Psi D \). The Stokes parameters can be interpreted as a representation in the Poincaré sphere, of the action of a liquid crystal device and is the most general method for geometrically represent the polarization states of a light beam and its transformations undergone by the action of a polarization system [11].
representation of the Poincare sphere, there is a univocal correspondence between the pure polarization states and points of the surface of the sphere surface as shown in Figure 2.

The Cartesian coordinates of each one of these points are the Stokes parameters $S_1, S_2, S_3$ of the $\Psi_D$, using the unique relationship between a state of polarization incident on the LCD and a point on the Poincare sphere [14]. Such analysis can be performed by determining the value of the Stokes parameters of the emerging light from the device using the following expressions [11]:

\[
S_0 = X^2 + Y^2 + Z^2 = 1
\]

\[
S_1 = (X^2 - Z^2) \cos[2(\phi + \zeta_1)] + 2XZ \sin[2(\theta + \zeta_1)] + Y^2 \cos[2\theta + 2\psi_D - \zeta_1]
\]

\[
S_2 = (X^2 - Z^2) \sin[2(\phi + \zeta_1)] - 2XZ \cos[2(\theta + \zeta_1)] + Y^2 \sin[2\theta + 2\psi_D - \zeta_1]
\]

\[
S_3 = -2Y(Z \cos[2(\phi + \zeta_1)] + X \sin[2\theta + 2\psi_D - \zeta_1])
\]

**Figure 2.** (a) Poincaré sphere representation of a polarization state. (b) Experimental setup for the measurement of the Stokes parameters. QWP: Quarter wave plate, it is used for measuring the parameter $S_3$. From reference [11].

### 3. Results

The experimental and theoretical results of the intensity obtained with Soutar-Lu technique are shown in Figure 3. In these results can observe a good correspondence between the theory and the experimental procedure. Finally, using a nonlinear regression $\Psi_D$ have the values shown in Table 1.

**Figure 3.** Experimental (red line) and theoretical (blue plot) curves obtained for (a) the parallel configuration, (b) cross configuration and (c) setting the ratio of the cross-configuration and the parallel configuration.
Table 1. Results for the TNLCD parameters using the Soutar-Lu method.

| Parameter                        | Value                        |
|----------------------------------|------------------------------|
| Twist angle (φ)                  | +93.8° or -93.8°             |
| The angle of the molecular axis (ΨD) | +75.1° or -14.9°             |
| The birefringence (β)            | 2.126 rad                    |

3.1. Determination the sign of the twist angle (φ) and the angle of the molecular axis (ΨD)

Using the stokes parameters can find the sign of φ and β [10]. The results obtained are presented theoretically and experimentally for Stokes parameters. The results obtained theoretically and experimentally for Stokes parameters are presented in the Figures 4 to 7. In these results can see that value of $S_3$ changes sign when $ΨD$ is replaced by $2π+ΨD$, while $S_1$ and $S_2$ remain invariant. Then the $ΨD$ was found from $S_3$ parameter. While the change sign of φ causes a modification in the value of the three parameters $S_1$, $S_2$ and $S_3$. For this reason using a combination of the value found of $ΨD$, the transmission curves and the stokes parameters is possible the sign of φ.

$-14.9°$.

![Figure 4](image1)

Figure 4. Experimental (blue plot) and theoretical (red plot) curves obtained for the Stokes parameters by adding $π/2$ to -14.9°. (a) $S_1$. (b) $S_2$. (c) $S_3$.

$+75.1°$.

![Figure 5](image2)

Figure 5. Experimental (blue plot) and theoretical (red plot) curves obtained for the Stokes parameters by adding $π/2$ to +75.1°. (a) $S_1$. (b) $S_2$. (c) $S_3$. 
For the twist angle (φ)+93.8°.

![Figure 6](image)

**Figure 6.** Experimental (blue plot) and theoretical (red plot) curves obtained for the Stokes parameters with twist angle +98.3°. (a) $S_1$. (b) $S_2$. (c) $S_3$.

-98.3°.

![Figure 7](image)

**Figure 7.** Experimental (blue plot) and theoretical (red plot) curves obtained for the Stokes parameters with twist angle -98.3°. (a) $S_1$. (b) $S_2$. (c) $S_3$.

Finally, the Table 2 show the final results obtained for the twist angle (φ), the angle of the molecular axis (ΨD), and the birefringence (β) when the LCD is off.

| Parameter                          | Value       |
|------------------------------------|-------------|
| Twist angle (φ)                    | +93.8°      |
| The angle of the molecular axis (ΨD) | -14.9°    |
| The birefringence (β)              | 2.126 rad   |

**Table 2.** Finals Results of the TNLCD parameters.

4. Conclusions

retarder-rotor model using the Stokes parameters. Therefore, a unique and unambiguous response without the application of an external voltage for the liquid crystal matrix LCX038ARA by transmission is obtained.
Acknowledgments

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References

[1] T Gould, J Myers and J Bewersdorf 2011 Total internal reflection STED microscopy Optics Express 19 13351-13357
[2] M Zhongsheng, M Changjun, S Zhu and X Yuan 2014 Tight focusing of quasi-cylindrically polarized beams Journal of the Optical Society of America A 31(2) 373-378
[3] T Ehmke, T Heiko, A Knebl and A Heisterkamp 2014 Molecular orientation sensitive second harmonic microscopy by radially and azimuthally polarized light Biomedical Optics Express 5(7) 2232-2246
[4] H Wang, X Zhenwei, Z Mile, C Haili, H Jingsuo, F Shengfei, W Xinke, S Wenfeng, Y Jiasheng, H Peng and Z Yan 2015 A miniaturized optical fiber microphone with concentric nanorings grating and microsprings structured diaphragm Optics and Laser Technology 21(1) 102-111
[5] Fujitsu 2006 Fundamentals of Liquid Crystal Displays – How They Work and What They Do (California: Fujitsu Microelectronics America, Inc.) pp 1-14
[6] C Zafra 2009 Caracterización,Modelado Eléctrico y Desarrollo de Nuevas Aplicaciones de Dispositivos Basados en Cristales Líquidos (Madrid: Universidad Carlos III de Madrid)
[7] E Martín B 1998 Correlador óptico para el reconocimiento de objetos basado en las propiedades de modulación de los dispositivos de cristal líquido (Barcelona: Universidad de Barcelona)
[8] J M Vilardy, M S Millán and E Pérez-Cabré 2013 Static and dynamic amplitude modulation of light in a twisted nematic liquid crystal display Proc. SPIE - Int. Soc. Opt. Eng. 8785 10
[9] H Fernández V 2008 Estudio y optimización del almacenamiento de información en una memoria holográfica (Alicante: Universidad de Alicante)
[10] C Soutar and K Lu 1994 Determination of the physical properties of an arbitrary twisted-nematic liquid crystal cell Opt. Eng. 33(8) 2704
[11] M Mora-gonzález and F J Casillas Rodríguez 2016 Comparación de Métodos de Calibración para Cristales Líquidos (Nemáticos) Investigación y Ciencia 14(36) 4-9
[12] M M González 2002 Aplicaciones de cristales líquidos a pruebas ópticas no destructivas (Guanajuato: Universidad de Guanajuato)
[13] V B Durán 2015 Optimización del Funcionamiento de un Modulador Espacial de Luz de Cristal Líquido Mediante el Modelo Retardador-Rotor. Aplicaciones en Óptica Adaptativa (Valencia: Universidad de Valencia)
[14] E Hecht 2002 Optics 4th edition (San Francisco: Pearson International Edition)