A novel method to study the twist dynamics in chiral nematic liquid crystals by texture analysis

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Abstract. We have experimentally studied the twist dynamics as a function of temperatures in chiral nematic liquid crystals by applying texture analysis to the image data observed by polarized light microscopy. These microscopic textures are analyzed using MATLAB software. The irregularity of texture at different temperatures observed by statistical parameter such as entropy indicate the changes of director orientation. Moreover, the changes in textural as a function of temperatures are useful to investigate the order parameter values of chiral nematic liquid crystals also to predict the behavior of twist dynamics. The order parameter values of the samples at different temperatures are obtained based on images intensity along twist-line using simple calculation then the behavior of twist dynamics are visualized. The study of dynamics of twist mode chiral nematic liquid crystals is important to observe the electro-optic effect in display technology or other applications.

1. Introduction

Liquid crystals are compounds having both characteristics like liquids and long range order like crystals. Two main classes of liquid crystals namely thermotropic and lyotropic liquid crystals. Typical of liquid crystal thermotropic phases are nematic, smectic, and cholesteric phases [1][2]. The cholesteric phase usually involves cholesteryl compounds shown in figure 1 [3]. The cholesteric liquid crystals have chirality of the molecules or twisted molecular arrangements, resulting in helical structures with certain periodicity. Another type cholesteric liquid crystal with non-cholesteryl compounds is chiral nematic liquid crystal. The phase may be categorized into nematic phases and called a chiral nematic phase [1][2][3].

On chiral or twisted molecular structure, it consists of quasi-nematic layers whose individual directors are turned by a fixed angle from one layer to the next layer. Each layer has different molecular direction. The distance of two layers with same orientation angle are equivalent to 2π namely pitch (p) as shown in figure 1. The helical pitch is thermally responsive to changing reflective colors [3].

Cholesteric liquid crystal or chiral nematic liquid crystal possesses a number of properties of unique optical effects referred that it is birefringent because of anisotropic characteristic [1][3]. For any anisotropic materials, different orientations respect to the molecular alignment may cause the incident light be transmitted with different velocities. When unpolarized light enters to chiral nematic, incident light selectively polarized, commonly become two directions namely ordinary polarized ray and extraordinary ray polarized [2][4][5]. In the case of chiral nematic liquid crystal sample with the
homogeneous planar alignment placed between two crossed polarizers, the texture appears completely black when the director is either parallel or perpendicular to the transmission axis of the polarizer or analyzer [2].

![Image](image.png)

**Figure 1.** Molecules alignment of cholesteric or chiral nematic structure

The study of dynamics of cholestersis is important in the context of applications that make use of the electrooptic effect [6][12]. A technique which combines image analysis and polarising optical microscope (POM) is a useful tool for the physical investigation of liquid crystals. Textural features of the samples provided the information approximately suitable to determine the optical properties of the samples such as optical transmittance, absorption coefficient, birefringence, and order parameter [6][12]. A new image processing method is developed in order to predict the behaviour of twist dynamics of chiral nematic liquid crystals based on entropy parameter using feature extraction and the order parameter value using simple calculation taken from statistical data.

2. **Experimental**

The chiral nematic liquid crystals with 50 μm spacing are obtained from sfx Inc without any treatment on orientational order. Temperature dependent textural investigations are carried out by polarizing optical microscope attached to hot stage. The color image detected by the camera which represents the true color pixel tone that ranges from 0 to 255 in RGB colors under crossed polarizer. To compute thermo optical properties, textures in RGB images converted to monochromatic images. We choose HSV image (hue, saturation, value) and only focus on value parameter to simplify the value of pixel tone that ranges from 0 to 1. Value (V) parameter represent the brightness of the color or on the other hand it is a representation of intensity. The higher value show the greater in intensity [13].

![Image](image.png)

**Figure 2.** (a) Side view of sample. (b) Instrumentation set-up
3. Results and Discussions

Figure 3 shows chiral nematic liquid crystal monochromatic textures at different temperatures. We observe no visual change until the temperature $T = 31.5 \degree C$. The textures change significantly at $T = 31.5 \degree C$ to $T = 32\degree C$. As increasing on temperature, we observe the regularity of patterns. The crossed patterns appear here caused by birefringence effect of chiral nematic liquid crystals and the consequence of polarizing light by crossed polarizer [1][3][15]. For further literature review, this crossed patterns namely double twist [16-19]. To verify this observation, we take statistical data based on images intensity as shown in figure 3, and applied first order feature extraction by entropy parameter using Matlab [13][14]. The graph of entropy value shown in figure 4.

![Textures at different temperatures](image1)

**Figure 3.** Experimental textures of an chiral nematic liquid sample at different temperatures.

Figure 4 shows the Entropy value as a function of temperatures. Entropy is a measure of the randomness of image intensity. The greater of entropy, the more irregular intensity of each pixel [13][14]. Near critical temperature ($T_c$), at $T_c = 31.5$, indicated by dash line at figure 5, the entropy extremely decrease which represent the regularity of pattern. We note that phase transition as shown in figure 3 is properly with the quantity result of entropy measures. In accordance with the visual observation based on figure 3, the maximum decreasing in entropy occurs until double twist patterns achieved experimentally at $T_c = 31.5 \degree C$.

It is obviously seen the change of texture through the increasing of temperature by figure 3. It might be possible to predict the dynamics of twist pattern by statistical data of intensity along twist-line. By simple method, we plot the various value of intensity along twist-line at different temperature and compare the results. It gives information about the intensity that transmitted by sample, the different intensity value means the different of director orientation. Hence, we can determine the director orientation by $\theta$ angle to the initial director ($\vec{n}$) [1][2][15].
Figure 4. Entropy value as a function of temperatures.

Schematic diagram showing the orientation of single rod-like molecules shown in figure 5. The orientation of a rod-like molecule can be represented by a unit vector \( \vec{a} \) which is attached to the molecule and parallel to the long molecular axis [15].

![Schematic diagram showing the orientation of single rod-like molecules](image)

**Figure 5.** Schematic diagram showing the orientation of single rod-like molecules [15]

Chiral nematic liquid crystal consists of quasi-nematic layers whose individual directors are turned by a fixed angle from one layer to the next layer. Each layer has different molecular direction [3]. A simple approach for observing the twist dynamics in chiral nematic liquid crystal consists by taking the order parameter equation in nematic liquid crystal by argument that the different intensity of images as a result of different orientation of director and the different orientation of director could be represented by order parameter \( S \). The order parameter is usually defined in such a way that it is zero in the high-temperature unordered phase and non-zero in the low-temperature ordered phase. The average value of the second-order Legendre polynomial for the order parameter for nematic liquid crystal shown in equation 1 [15].

\[
S = \frac{1}{\sqrt{3}} \left( 3 \cos^2 \theta - 1 \right)
\]

Based on equation 1 we note that \( S = 1 \) is a condition for the orientation of molecules parallel with the initial director \( \vec{n} \) and correspondent to the maximum intensity value of images. Otherwise, \( S = -0.5 \) is for isotropic states and correspondent to the minimum intensity value of images [15].
Figure 6. Schematic diagram showing the states with different order parameters for $S = 1$ and for $S = -0.5$ [15]

Applying the normalization of intensity value along line segment of twist-line we get $\theta$ value variation between $0 - 90^\circ$ and then using equation 1 to calculate the $S$ value. The example of taking a line segmentation along double twist pattern shown by figure 7.

Figure 7. Line segmentation along double twist pattern for (a) $T = 28 \, ^\circ\text{C}$ and (b) $T = 35 \, ^\circ\text{C}$ shown by arrow symbols.

Figure 8 illustrate the various value of order parameter between -0.5 to 1. For a line segmentation in figure 7, we note that $S = 1$ defines the bright images correspondent to $\theta = 0^\circ$ and $S = -0.5$ for dark image correspondent $\theta = 90^\circ$ as illustrated in figure 6.

To simplify the analysis we only choose the result for $T = 28 \, ^\circ\text{C}$ and $T = 35 \, ^\circ\text{C}$ which initial and final temperature in the range of experimentally set up. Consider only the region between dash lines vertical in figure 7, the different of order parameter value between dash lines vertical show the dynamic of twist-line at higher temperature. For $T = 28 \, ^\circ\text{C}$ the similar value of $S$ represent the similarity of intensity image along line segmentation of twist pattern, it means that the all the director orientation parallel to $\hat{\mathbf{n}}$, based on figure 7a it obviously seen as bright image or maximum intensity along line segmentation.

Figure 8. Comparison of order parameter along twist-line for $T = 28 \, ^\circ\text{C}$ and $T = 35 \, ^\circ\text{C}$. The different on value between dash lines vertical show the dynamic of twist-line at higher temperature. The decreasing of order parameter represent to the different orientation of director along twist-line.
Reinitzer in 1888 observed under a polarizing microscope a mesogenic compound made of chiral molecules and noticed blue colour phenomenon, which appears and then quickly disappears but still liquid. It was exhibited in the narrow temperature range between the chiral nematic and the isotropic phases. Thus blue phases appear as the three-dimensional counterpart of chiral nematics. The blue phases are generated by double-twisted cylinders separated by defect lines. De Gennes introduce the schematic of director orientation in double twist pattern as shown in figure 8 [2][16][17][18][19].

\[ \text{Figure 9. Schematic representation of a double twist.}[2] \]

As temperature increased or decreased, the texture change depending on alignment of molecules in sample. At the lowest temperatures the texture remains same like solid phase (shown in figure 7a) with \( S = 1 \), and at the highest temperatures the texture remains tend to isotropic phase by appearance of dark color (shown in figure 7b) with \( S \ll 1 \). In isotropic phase, the destruction of molecular alignment from their respective phases causes the disappearance of birefringence property and it leads to the decrement of Birefringence value. On the other hand, the various value of \( S \) illustrated in figure 7 at \( T_{\text{max}} = 35^\circ \text{C} \) bring to the decrement of Birefringence value. The minimum of \( S \) indicate the absence of Birefringence and it cause the appearance of dark color.

For further analysis we can predict the behavior of molecular alignment based on the graph of figure 7. There is no change in molecular alignment at \( T = 28^\circ \text{C} \), all directors have similar orientation. If we choose vertical axis for director orientation at \( T = 28^\circ \text{C} \) then directors orientation for \( T = 35^\circ \text{C} \) will various in \( \theta \), which \( \theta \) is the angle director orientation in vertical axis to the final directors orientation as shown in figure 5. Figure 9 is an illustration of molecular alignment at \( T = 28^\circ \text{C} \) and \( T = 35^\circ \text{C} \).

\[ \text{Figure 10. Schematic of molecular alignment at (a) } T = 28^\circ \text{C} \text{ and (b) } T = 35^\circ \text{C} \]

The schematic shown in figure 9 is an approach for one double twist pattern, it is clear that there are many patterns that appears on microscopic image in chiral nematic liquid crystal sample. Theoretically, the value of order parameter \( S = 1 \) means all of directors align at similar orientation [15]. However we only draw molecular orientation in figure 9a in accordance with the molecular orientation in figure 9b so that we can distinguish the patterns easier. The illustration in figure 9b is not exactly similar to the order parameter value in figure 7, in fact it might be different. However, the difference of schematic as shown in figure 9a and 9b illustrate qualitatively the twist dynamics between range of temperatures at \( T = 28^\circ \text{C} \) until \( T = 35^\circ \text{C} \). It approximately suitable to the theoretical as derived as double twist schematic in figure 8 [2].
4. Conclusions

Textural of the samples microscopic images as function of temperatures provide the information approximately suitable to determine the optical properties of the chiral nematic liquid crystal sample based on the difference of intensity of texture. As increasing on temperature, the change of patterns appear caused by birefringence effect of chiral nematic liquid crystals and the consequence of polarizing light by crossed polarizer. Entropy parameter useful to illustrate the irregularity of intensity value in monochromatic images. It derive to the argument that there are difference in director orientation of molecules alignment on sample. The graph of entropy as temperature function gives us information about critical temperature from chiral nematic to isotropic phase, which a double twist pattern appear. Moreover, Approach to nematic liquid crystal to calculate the order value parameter. The various of order parameter value derive the prediction of twist dynamics in range of temperatures set up. Based on the behavior of order parameter value, we can illustrate the schematic of molecular alignment to observe clearly the twist dynamics at lowest and highest temperature.

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