Image Feature Extraction Method to Analyze Soft-Mode Turbulence Fluctuation in Nematic Liquid Crystal

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Abstract. An electroconvective pattern called soft-mode turbulence (SMT) of homeotropic alignment in MBBA (4'-Methoxy-benzylidene-4-butyl-aniline) nematic liquid crystal appears when an external electric field with a certain frequency applied on the nematic liquid crystal sample at a threshold voltage (V_{SMT}). The threshold voltage will increase with increasing of frequency. SMT fluctuation occurs when V_{SMT} continues to increase at the same frequency. This phenomenon can be analyzed by applying an image processing technique. Based on image feature extraction method, inhomogeneity of SMT patterns can be observed through contrast, correlation, energy, homogeneity, and entropy parameters. Those parameters represent a result in accordance with the image visualization. Significant changes in the value of contrast, energy, homogeneity, and entropy parameters occur at V> V_{SMT} which fluctuation begin. In this experiment the fluctuation begin at V = 27.3 V.

1. Introduction
Liquid crystal has a good response to the external field such as temperature, electric fields, and magnetic fields. In equilibrium and without an external field influences, nematic liquid crystal molecules are oriented in one direction called the (n) director. The responses of nematic liquid crystal to electric field can be studied by placing liquid crystal material between an ITO (Indium Tin Oxide) parallel glass plates as an electrode. There are two typicals of nematic liquid crystal alignments namely planar and homeotropic. Director n has an initial director in the x-axis (n = 1, 0, 0) in a planar alignment, and z-axis alignment (n = 0, 0, 1) in a homeotropic alignment [1,2]. The external force can cause distortion along the uniaxial axis of the director in nematic liquid crystal. There are three typicals of deformations namely splay, bend and twist, as shown in figure 1 [2].

Figure 1. (a) splay (b) twist and (c) bend deformation of nematic liquid crystal
When a DC or AC electric field is applied between two electrodes, the ionic particles in nematic liquid crystal will move periodically due to the influence of the field. This phenomenon is known as electro-hydrodynamic instability (EHD). EHD appears when the voltage greater than threshold voltage \( V_{EHD} \) applied to nematic liquid crystal layer [2]. The effect of EHD is a response that given by a nematic liquid crystal because of its anisotropy properties. The effect of EHD is indicated by the formation of various convective patterns, in the form of dark-light lines. The effect of EHD occurs because of the reorientation of the direction of the liquid crystal molecules. The physical mechanism in EHD is described by Carr (1969) and Helfrich (1969) in the Carr-Helfrich (CH) mechanism as shown in figure 2.

\[ V^2_{EHD} = V_0^2 \left( 1 + f^2 \tau_c^2 \right) \left( \xi^2 - 1 - f^2 \tau_c^2 \right) \]

\( \xi \) is Helfrich constant and \( \tau_c \) relaxation time of charge.

Equation 1 shows that the threshold voltage increases with increasing of frequency and tends to infinite when the frequency approaches the critical frequency value \( f_c \).

\[ f_c = \frac{1}{\tau_c} \sqrt{\xi^2 - 1} \]

Zaman conducted a study on the effects of EHD on homeotropic samples of MBBA nematic liquid crystals [3].

\[ f_L \approx 700 \text{ Hz} \]
Zaman show the convection phenomenon when the voltage exceeds the threshold voltage at a certain frequency, which is called the soft-mode turbulence (SMT). There are two types of SMT namely oblique rolls (OR) and normal rolls (NR) which shown in Figure 3. The graph of threshold voltages as a function of frequency modulation also shown in Figure 3 [3].

There are many ways to analyze the image of SMT patterns captured using polarizing microscope. Narumi, et al., observed SMT relaxation by measuring a temporal autocorrelation function of patterns dynamic in SMT to observe the spatial-temporal chaos in homeotropically aligned nematic liquid crystal. They reported that the relaxation well fitted by a compressed exponential function [4]. In our study, we will analyze the patterns of SMT at various voltages. We introduce a method in image processing namely image feature extraction to distinguish the texture of patterns based on statistical data extraction. There are two typicals of image feature extraction, first order feature extraction (for example mean, variance, skewness, kurtosis and entropy parameters) and second order feature extraction (for example contrast, correlation, angular second moment, and energy parameters) [5].

2. Method

Nematic liquid crystal sample with 50 μm of thickness and homeotropic alignment placed in a hot stage at a constant temperature. An electric field in the z axis direction applied to the sample. The EHD effect that appears on the sample is observed using a polarizing microscope by adjusting the frequency modulation. At the certain frequency, the voltage is adjusted until a soft mode turbulence (SMT) pattern appears. At the same frequency, the voltage continues to be increased for fluctuations observation.

We use Matlab software to analyze the images. The RGB images is converted to HSV images to simplify the values. HSV contains of the hue, saturation, and value components for the image. The value parameter is selected to show the level of darkness or brightness of images (value-image). The value components express the brightness of the color. The value parameter is in the range 0-1 from black to white. Then the gray-level co-occurrence matrix (GLCM) process applied to value-image. According to the gray-level co-occurrence matrix (GLCM) process, quantitative data can be extracted, namely image feature extraction, with statistical parameters like contrast, correlation, energy, and homogeneity. We also compare with another statistical data parameter like entropy value [6].

3. Result and Discussion

Figure 5 shows the graph of SMT voltage ($V_{SMT}$) as a function of frequency. Approach a critical frequency, the threshold voltage value will be greater than before. The graph as in figure 5 accordance
with equation 1 which the increasing of threshold voltage is not linearly proportional to the critical frequency. Since the voltage is applied to the sample, then it is raised slowly, the liquid crystal molecules continues to move because its physical properties as an anisotropic substances. The emergence of the SMT pattern is characterized by the formation of a darker color on the sample than the previous one. After a contrast different color appear, the voltage is raised more slowly so that the threshold voltage which SMT pattern appearance can be determined precisely. Electroconvection pattern appears in the homeotropic alignment in the same manner as the tilted director appears in the planar alignment.

![Figure 5. SMT voltage \(V_{\text{SMT}}\) as a function of frequency](image)

If the voltage continues to be increased, there will be fluctuating, as shown in Figure 7. In the homeotropic sample, if the voltage is increased greater than the critical threshold voltage, the elastic free energy density also tend to increase and the orientation of the director becomes more fluctuating.

![Figure 6. SMT fluctuations at \(f = 200\) Hz. (a) SMT pattern at the threshold voltage \(V_{\text{SMT}} = 26.6\) V. The voltage continues to increase with \(\Delta V = 0.2\) V. (j) SMT pattern at \(V_j = 28.5\) V](image)

Fluctuations in the SMT pattern as shown in figure 6 can be quantitatively shown by applying feature extraction method to the image using Matlab software.

The result of the first order feature extraction, according to entropy parameter, can be shown in the graph of entropy as a voltage function in figure 7. Entropy is a measurement of the image intensity randomness. The greater of the entropy the more irregular intensity of each pixel, as shown in figure 7. The decreasing of entropy parameter occurs when fluctuations begin at \(V = 27.3\) volts.
Figure 7. Texture entropy as a function of voltage when 200 Hz frequency applied (V > V_{SMT})

Second-order feature extraction can be used to distinguish the texture of an image from another images through parameters such as contrast, correlation, energy, and homogeneity. The results of the second order feature extraction based on statistical data of these parameters are shown in figure 8 and figure 8 and 9.

Contrast parameter is a measurement of the local variations in the gray-level co-occurrence matrix. It measures of the intensity contrast between a pixel and its neighbor over the whole image. Contrast parameter is also known as variance and inertia. The graph in figure 8a shows that the value of the contrast increases with increasing of voltage, it indicates the greater of the difference in intensity between pixels, in accordance with Figure 7. At \( V = 27.3 \) volt, the contrast value tend to decrease (figure 7f). Based on the image in figure 7, it appears a change of significant pattern in figure 7e to 7f where the fluctuations occur.

Based on the graph of correlation, energy and homogeneity parameter, in figure 8a, 9a and 9b, it can be shown that the values of those parameters decrease as a function of the voltage. Correlation parameter is a measurement of the joint probability of occurrence in specified pixel pairs. Decreasing of correlation values shows that the relationship between pixels has a low recurrence probability.
Figure 9. (a) Texture energy as a function of voltage, and (b) Texture homogeneity parameter as a function of voltage, for 200 Hz in frequency ($V > V_{SMT}$).

Energy parameter is also known as angular second moment (asm) which measures the uniformity of pixels. Decreasing of energy parameter values show an increasing of inhomogeneous pattern. Homogeneity parameter is a measurement of the closeness of the elements distribution overall to the diagonals so that the lower homogeneity values show the non-homogeneity of the distribution of pixels.

The graph of energy and homogeneity parameters in figure 9 also shows that at $V = 27.3$ V the intensity value increases again. This behavior appropriate with the contrast parameter where the increasing of intensity occur significantly when fluctuation begin, as shown in figure 7e to 7f.

4. Conclusion

Fluctuations in soft-mode turbulence patterns at the same frequency occur when the voltage greater than the threshold voltage. Soft-mode turbulence fluctuation can be observed by extracting image characteristics, both first order and second order feature extraction. Contrast, energy, homogeneity and entropy parameters represent a result in accordance with image visualization. There is a significant changes of the contrast, energy, homogeneity, and entropy parameters when the voltages greater than the threshold voltage which fluctuations begin to occur. In this experiment the fluctuation begin at $V = 27.3$ V. Based on the values of contrast, energy, homogeneity and entropy parameters it can be shown that when the voltage that applied to the sample greater than the threshold voltage, the irregularity in intensity of images will be increase and also indicates the fluctuation of the molecules movement on sample because of an anisotropic properties in nematic liquid crystal.

5. References

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