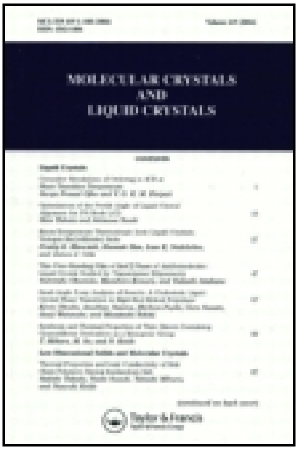

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

EDGE DETECTION WITH LIQUID CRYSTAL POLARIZING FILTER

Andrzej Walczak [a], Edward Nowinowski-Kruszelnicki [a], Leszek R. Jaroszewicz [a] & Radoslaw Wal [b]

[a] Institute of Applied Physics MUT, 00-908 Warsaw, 2 Kaliskiego St., Poland

[b] Institute of Automation and Robotics MUT, 00-908 Warsaw, 2 Kaliskiego St., Poland

Version of record first published: 07 Jan 2010

Mol. Cryst. Liq. Cryst., Vol. 413, pp. 407/[2543]–415/[2551], 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490438924

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Andrzej Walczak, Edward Nowinowski-Kruszelnicki, and Leszek R. Jaroszewicz
Institute of Applied Physics MUT, 00-908 Warsaw, 2 Kaliskiego St., Poland

*Radosław Wal**
Institute of Automation and Robotics MUT, 00-908 Warsaw, 2 Kaliskiego St., Poland

The liquid crystalline filter exhibiting particular optical properties is presented. Their basis application is the multiresolution image analyzer based on a wavelet transform (WT). In co-operation with the phase shifter such a filter allows to rotate the polarization of the transmitted light. The resulted intensity distribution has been exploited as a tool to span the transmitted image onto the space of the circular Haar wavelets. It provides new possibilities in an optical signal processing. The analysis of the light transmission in considered filter as well as the wavelet space creation are also described.

Keywords: edge detection; haar wavelet; image processing; liquid crystal; polarimetric imaging

INTRODUCTION

The objective of edge detection is to locate the boundaries of the object of interest in an image. This usually involves efforts to search of intensity discontinuities and some method for linking edge points into boundary curves. A few methods are commonly used for that aim [1–3]. All of them have to apply an image derivatives taken over the intensity distribution. The proper net for the derivative location must be chosen over the image before calculations. It decides about final results and makes them highly influenced by an applied method. The new way is proposed aided with the liquid crystalline device.

This work was sponsored by grants of MUT no. PBW 751 and PBS 636.
*Corresponding author. E-mail: awalc@iar.wat.waw.pl

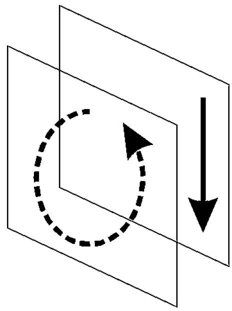

FIGURE 1 The scheme of the NLC director alingnment inside the circular filter.

We consider a liquid crystalline sandwich filled with a nematic liquid crystal (NLC). The alignment of the NLC molecules is parallel on the one side of the sandwich while on the second the alignment is circular in accordance with the scheme in the Figure 1. Such an alignment has been described already by Sato, Nose and Yamaguchi [4].

Along radial directions measured from the middle of the NLC sandwich area towards its the local twist structure of the alignment in obtained. On the each radius directed in such a way the twist angle remains the same. Along the each circle centered in the middle of the sandwich that twist angle varies smoothly with period equal to π. As polarized light passes across the NLC layer aligned in such a manner then the light transmission is like in the Figure 2.

Filter presented in the Figure 2 has been put onto polarizer sheet and covered with a crossed analyzer. The arrow seen in the picture, points out the alignment direction on the parallel-aligned side of the filter. The optical axis of the polarizer sheet in the Figure 2 is directed along its slanted edge. The light reflected in the filter area in the Figure 2 is polarized so it can be transmitted only through those parts of the filter in which the light transmission is allowed by a local twist (see formula (1) in further text).

It will be demonstrated that the transmission in such a filter creates special kind of functions, which can be used in a signal processing alternatively to the Fourier transform (FT). Those functions are called wavelets. Such supposition but in completely different meaning and manner has been proposed also by He, Honma, Masuda, Nose, and Sato [5].

The FT transforms a signal into two series of the triangular functions $\sin \omega t$ and $\cos \omega t$. These functions create the base on infinity extensions along t-axis. Thus, the FT gives sufficient precision for the stationary signals with a long segments. In many applications, however, we need to process signals with short segments such as speech, CCD pictures, seismic

FIGURE 2 The circular NLC filter onto the polarizing sheet and seeing by means of the analyzer.

waves, electrocardiograms, edges and so on. The FT depends on the cancellation of the periodic modes outside the localization of the signal, which requires more Fourier modes. Thus, the FT suffers higher frequency noise.

The wavelet transform (WT) is a new way to represent a signal by localizing it in both time and frequency domains. So it stands to be efficient in the analysis of a short transient signals [6]. It turned out to be especially convenient for an extraction of the image detail features.

One of the most complicated tasks in the image analysis is so called segmentation it means pulling out the area of the observed object which can be distinguished in some sense. In the presented filter such an operation is made immediately by the polarization of the transmitted light. These parts of the observed object which reflect the incident light in the same manner creates the same state of the reflected light polarization. Usually such parts are the planes existing in an observed object. Described filter transmission is polarization affected so the edges between areas with differently reflected or transmitted light polarization are possible to detect.

PROPERTIES OF THE LIQUID CRYSTALLINE CIRCULAR FILTER (LCCF)

The transmission in each point of the considered filter is described by the formula [7].

$$
\begin{aligned}
T = {} & \cos^2(\phi - \phi_{exit} + \phi_{ent}) + \sin^2 X \sin 2(\phi - \phi_{exit}) \sin 2\phi_{ent} \\
& + \frac{\phi}{2X} \sin 2X \sin 2(\phi - \phi_{exit} + \phi_{ent}) \\
& - \phi^2 \left(\frac{\sin X}{X}\right)^2 \cos 2(\phi - \phi_{exit}) \cos 2\phi_{ent}
\end{aligned} \tag{1}
$$

where

$$
X = \sqrt{\phi^2 + \left(\frac{\Gamma}{2}\right)^2} \quad and \quad \Gamma = \frac{2\pi}{\lambda}(n_e - n_o)d
$$

The angle ϕ is equal to a reference angular position between entrance and exit NLC director while ϕ_{exit}, and ϕ_{ent} are exit and entrance polarizer inclination. As polarization of the incident light rotates then an area of the maximum transmission in the filter also rotates in plane of the filter because of the angle ϕ_{ent} variation. The same result will be obtained if the analyzer rotates. In a static crossed position of polarizer and analyzer the described filter produces the light transmission with lowest and highest extremes creating “a four-petal flower”. In the device arranged as in the Figure 3 a rotation of the transmission area of the filter is obtained by a usage of the tuned liquid crystalline phase shifter, which is placed between polarizer and the LCCF.

If the polarization of an incident light beam is disturbed in a certain area of the image, then this area will be observed in the LCCF window as a changed light intensity. To illustrate this phenomenon an experiment has been set up. In the device like in the Figure 3 two prisms have been grouped between the polarizer and the LCCF body. It should produce changes in

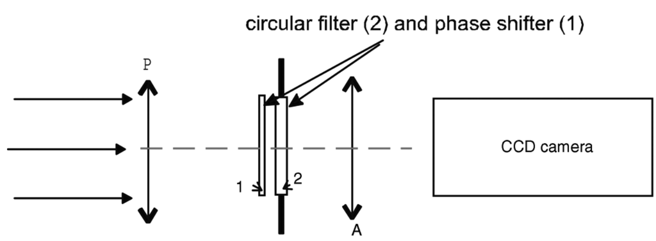

FIGURE 3 The scheme of the device used in edge detection by means of the LCCF filter.

the polarization of the incident light beam. These changes are related to prism's wall inclination. So parts of the LCCF window laying above prism's walls will change the transmitted light intensity in the dependency on a driving voltage in the phase shifter shown in the Figure 3. Results of the observations are illustrated in the Figure 4.

It is easy to see that edges dividing prism's walls can be seeing well or worse in the dependency on the transmitted polarization. So rotation of the "four-petal flower" area of the transmission, which is in fact a rotation of the transmitted polarization, is a tool for a detection of the edges in the observed image. The condition is that those edges have to divide such parts of the image, which reflect or transmit waves with a different polarization.

In fact to make mentioned segmentation one should extract details of the observed edges from the image. Below the special way for doing it is proposed. As far as author knew this is an innovative approach for edge

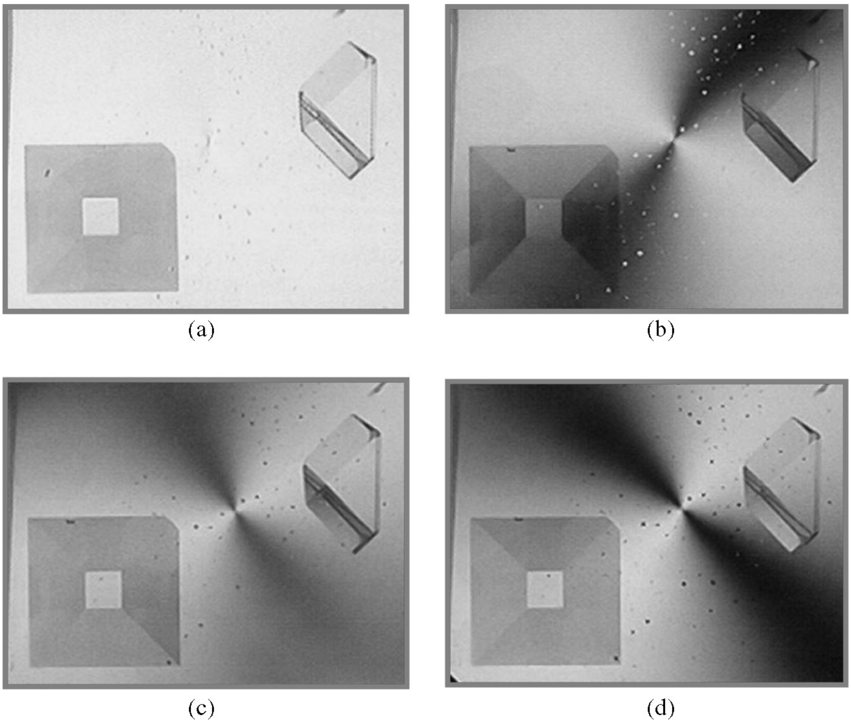

FIGURE 4 View of the prism placed between the polarizer and the phase shifter: a) as the analyzer is absent, b) as the analyzer is present and the phase shifter is in off state, c), d) while the phase shifter is driven by a different U_1 and U_2 voltages.

detection by means of the liquid crystalline device. It is based on the wavelet transform.

WAVELET TRANSFORM DEFINITIONS IN TIME-FREQUENCY DOMAINS

The basis functions of a WT, called wavelet, $h_{a,b}(t)$, are generated by dilation and translation from so called mother wavelet $h(t)$:

$$h_{a,b}(t) = \frac{1}{\sqrt{a}} h\left(\frac{t-b}{a}\right) \tag{2}$$

The variable t can be treated as generalized one as it may describe a space coordinate as well. The WT of the signal $s(t)$ is defined as an inner product in the Hilbert space of the L^2 norm:

$$W_s(a,b) = \langle h_{a,b}(t), s(t) \rangle = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} h^*\left(\frac{t-b}{a}\right) s(t) dt \tag{3}$$

The integral (2) correlate the signal and the dilated wavelets. The $W_s(a, b)$ can be considered as functions of the time shift b for each fixed scale a that display the information $s(t)$ at various level of the resolution. That is a reason for calling the wavelet transform a multiresolution signal processes. As the dilation factors approaches 0, the wavelet W becomes more concentrated about $t = b$ by a compression but still has the same energy as the original function, because the factor $1/\sqrt{a}$ becomes high. The $W_s(a, b)$ then displays the small-scale high-frequency features of the signal $s(t)$. As a factor a increases, the coarser low-frequency features are displayed. Wavelets must fulfil the admissible condition as well as must be a regular.

As we put the circle in the center of the transmitted intensity (see Fig. 4 and Fig. 6) versus LC plate (ϕ, r) co-ordinates its dependency along the circle line in one half of the circle my be estimated by a function of the form of the bipolar step function:

$$h(\phi)_{|r=const} = rect\left[2\left(\phi - \frac{\pi}{4}\right) - rect\left[2\left(\phi - \frac{3}{4}\pi\right)\right]\right] \tag{6}$$

This kind of function is known as the Haar wavelet [5]. Along each circle centered in the middle of the LCCF one can put such a function. It is the mother wavelet. Such a function allows us to create wavelets space $h_{a,b}(\phi)$ over a circle with an arbitrary chosen radius r. The transformed

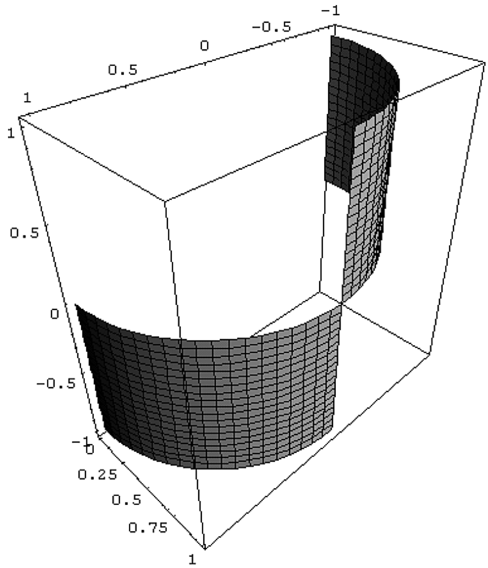

FIGURE 5 The circular Haar wavelet h(ϕ) plotted along an arbitrary chosen circle centered in the middle of the LCCF. Vertical axis is scaled from -1 to 1 value of the Haar function while horizontal axes are scaled in radians.

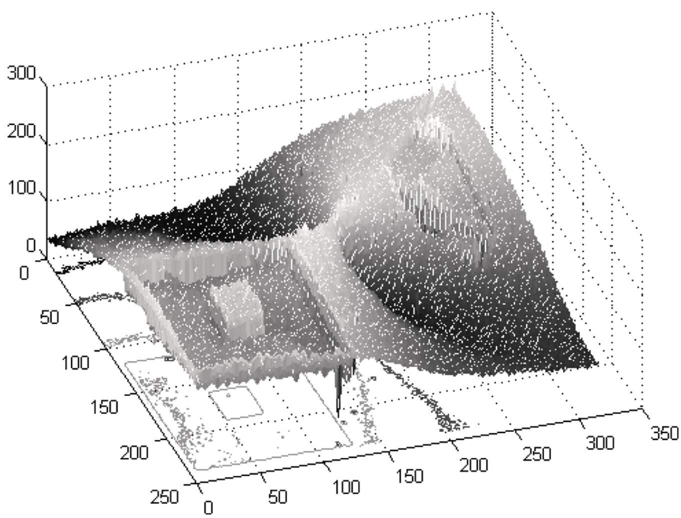

FIGURE 6 The transmission s(r, ϕ) measured (see Fig. 4d) after digitalization as the intensity levels. Horizontal axes are scaled in pixels. Intensity (vertical axe) is described in arbitrary units.

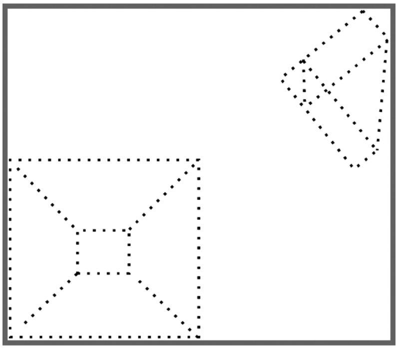

FIGURE 7 The edges extracted by means of the wavelet transform.

function *s(t)* from the formulae (1–3) is now registered as $s(r, \phi)$. The example of that function is of the form presented in the Figure 6. The WT with proposed wavelet is made over the circle with a constant radius r. Full transform is the sum over number of such circles. The wavelet transform has been done along each circle expanded from the middle with the step dr. So the transmitted light intensity $I(r, \phi)$ can be transformed in accordance with WT along the each circle centered in the middle of the image. The intensity discontinuities seeing as the edges result in jump in the WT [8–10]. Finally, as an illustration, dots along the edges and the mentioned circles crosses have been obtained like in the Figure 7. Each dots in the Figure 7 is connected with WT jump coordinates by the software created for the analyze.

These edges are present in the prisms. Now we can understand that the LCCF delivers a polarization sensitive image intensity distribution as well as allows the creation of the mathematical tool for the object recognition. Detailed image analysis is not the topic of this article so it is given only for the illustration of the LCCF useful features.

CONCLUSIONS

The new application of the optical filter with a particular alignment of the LC layer has been described. We call it liquid crystalline circular filter (LCCF) for its optical features. It has been exhibited how it may be applied in a new way. Demonstration of this filter as a tool for edge detection has been especially presented, and for this purpose a device for CCD image registration has been built (see Fig. 3) and the light path has been disturbed to change the polarization in parts of the illuminated area of the LCCF.

The way for creation the space of the wavelet functions in considered LCCF filter has been described in details with illustrating creation of the circularly arranged Haar wavelet. Advantages of the wavelet application in analysis of such signal, as CCD (between the other) has been shortly sketched, as well as the final result of the circular wavelet transform of the CCD image registered during the experiment. It has been confirmed that the LCCF is an efficient tool for elevation all disturbances of the polarization in the illuminated area of the LCCF. This feature of the LCCF can be applied for edges extraction in the registered images. The proper software is a component of the device. The LCCF and other optical components are "the hardware part".

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