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Correlation based rotation-invariant corner detector

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Abstract. In this work we introduce a new approach for corner extraction. The method that allows the corner extraction with rotation invariance is composed by a spiral phase function and a binary amplitude. The designed function can be easily implemented as a filter for a Vander Lugt-like optical correlator. A final image obtained with the detector presents intensity peaks in each corner location. Numerical simulation has been performed on a set of synthetic scenes, modulated either in amplitude or phase. Results that show the very good performance of the method are shown.

Keywords: Image processing, Fourier optics, Feature extraction
PACS: 07.05.Pj, 42.30.Kq, 42.30.Va, 42.79.Hp

1. INTRODUCTION

Corner detection, together with edge extraction are among the most popular feature extraction tasks as is well established by the abundant bibliography in image processing [1–6].

One of the most studied corner detector is based on the 2D Haar wavelet transform. This method consists in the correlation between the input scene and a 2D Haar wavelet. The optical implementation of correlation methods is a very good alternative when the processing time is a priority. An optical implementation of the Haar wavelet transform in a joint transform correlator (JTC) has been proposed [7]. Also the Vander Lugt architecture has been used to implement the Haar corner detector optically [8].

The corner detector based on the Haar wavelet is highly sensible to azimuthal rotations of the input, therefore it is not suitable to process rotated scenes, or scenes composed by differently rotated elements. Two recent works have addressed rotation invariance in optical edge detection employing a spiral phase filter [9, 10]. In the present work, we propose a new optical corner detection method based on a spiral phase filter.

We have tested our method with both amplitude and phase scenes. The good performance of the method for phase scenes supposes a promising application to microscopy of transparent samples.

In section 2 we present the design of the proposed filter, and in section 3 the results that shows the good performance of the method, are presented. Finally we summarize our work in section 4.

2. CORNER DETECTION

The proposed method consists in processing the input image to obtain a final image that shows sharp intensity peaks in the location of the corners. We propose here a filter that is based on a spiral phase. A spiral phase filter with an azimuthal period of 2π is a good edge enhancer as has been demonstrated in recent publications [9, 10]. We show here that a spiral phase filter with azimuthal period π behaves as a corner enhancer. The corner detection property of this filter can be more clearly understood by analyzing the symmetry of its impulse response. In fact, there is a family of filters that have a symmetry that is analog to the characteristic symmetry of the Haar filter. In terms of the Haar kernel

$$\mathrm{H} = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}, \tag{1}$$

these filters will act as corner extractors if their impulse response follows an amplitude distribution consisting in four central maxima with the phase relations given by the Haar kernel of Eq.(1). Both the real and the imaginary parts of the

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impulse response of the proposed spiral phase filter belong to this family of filters. Both components have a relative rotation angle of 45 degrees which confers the rotation invariance to the complex detector.

2.1. Filter design

As the π periodic function is also periodic in 2π, the proposed filter enhances both edges and corners of the input scene. With the aim of obtaining only the corner information, a binary amplitude band-pass filter was combined with the spiral phase shown in Fig. 1.a). The objective of this work is obtaining rotation invariance, then the amplitude filter must also be rotation invariant. Therefore a ring-shaped amplitude filter as depicted in Fig. 1.b) was employed. As the corners are related with the higher spatial frequencies of the object, the high cutoff frequency of the filter was set to its maximum value, corresponding to $R_{max} = 256$ pixels. The low cutoff frequency of the filter was left as a parameter R_{min} to be determined according to performance criteria of the corner detector.

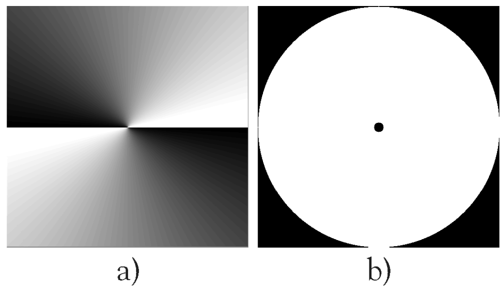

FIGURE 1. a)Spiral phase with π azimuthal periodicity, b)Annular binary band-pass filter with $R_{max} = 256$ pixels and $R_{min} = 10$ pixels.

We have established a set of criteria to evaluate the performance of the corner extractor. If the method is to be used in an automatic detection process, the peaks should be as high as possible in order to require no special specifications for the optical detector. Besides, each corner may yield the same peak intensity to assure the detection of all the corners in the scene. The spatial resolution in the location of the corners is dominated by the width of the peaks, then it should be minimized. Finally, to decide which height of a peak corresponds to a corner, a threshold must be selected, and in order to reduce the number of false positives the difference between the peak height and the maximum value of the background should be maximized.

We have employed four parameters to quantify these criteria as follows: The average peak height(APH), the standard deviation of the peak values(SDPH) within the input scene, the full width at half maximum(FWHM), and a parameter Δ defined as

$$\Delta = \frac{C_{max} - B_{max}}{C_{max}} \qquad (2)$$

where C_{max} is the maximum peak value and B_{max} is the maximum value of the background. This parameter decreases to zero when the background is as high as the maximum peak. On the other side, when no background is present in the final image, Δ reaches the value 1.

3. RESULTS

We have employed the binary synthetic scene shown in Fig. 3.a) to study the behavior of the filter. Numerical simulation of the optical corner detection have been calculated with this image as the input scene and the complex filter. The filter is composed by the spiral phase and the amplitude band-pass filter described above.

For each filter with R_{min} values ranging from 1 to 30 pixels, the peaks corresponding to all the 40 corners in the input scene were calculated. In Fig. 2.a) the APH in the output image is graphed as a function of the R_{min} value. As it could be noted, the peak values decrease as the cutoff frequency R_{min} is increased. This is an expected result as the energy that reaches the output is proportional to the area of the filter plane. In Fig. 2.b) the standard deviation (SDPH) of the peaks in the output image is computed and graphed vs. the cutoff spatial frequency. The curve shows that the peaks become more homogeneous as R_{min} increases. The third graph, in Fig. 2.c) shows the behavior of the parameter Δ vs.

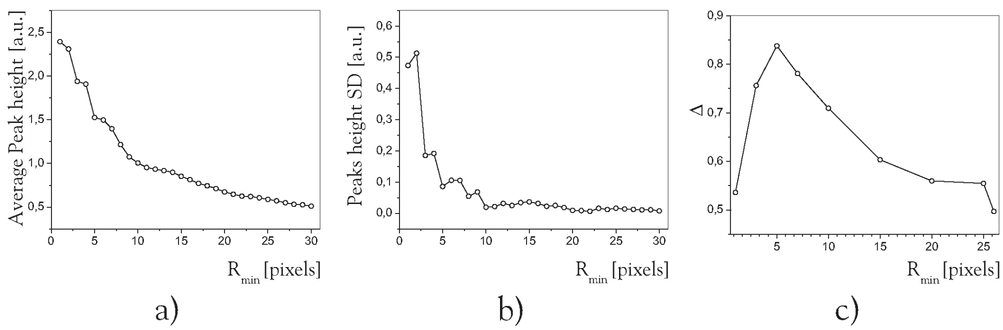

FIGURE 2. Results from numerical simulations: a) Standard deviation of the intensity peaks within each output image, b) Average of the intensity peaks within each output image, and c) parameter Δ of eq.(2).

the low cutoff frequency. It presents a maximum value for $R_{min} = 5$ pixels. Regarding the FWHM we have observed that the peaks remain between 4 and 5 pixels wide for values of R_{min} between 5 and 25 pixels. For that reason it does not affect significantly the selection of R_{min}. The exact value of R_{min} has to be determined according to the specific requirements of the application, and the importance of each parameter must be established. As an example, we show the performance of the method for a $R_{min} = 10$ pixels.

The impulse response of the filter, composed by a spiral phase function of azimuthal period π and a band-pass binary amplitude of cutoff frequency $R_{min} = 10$ pixels is correlated with the input scene of Fig. 3.a). The results for azimuthal rotation angles of the input scene: 0, 30 and 45 sexagesimal degrees are shown in figs. 3.b) to d) respectively. To compare these results with the traditional Haar wavelet method, the Haar wavelet transform of the same three angular rotations of the input scene are displayed in figs. 3.e) to g).

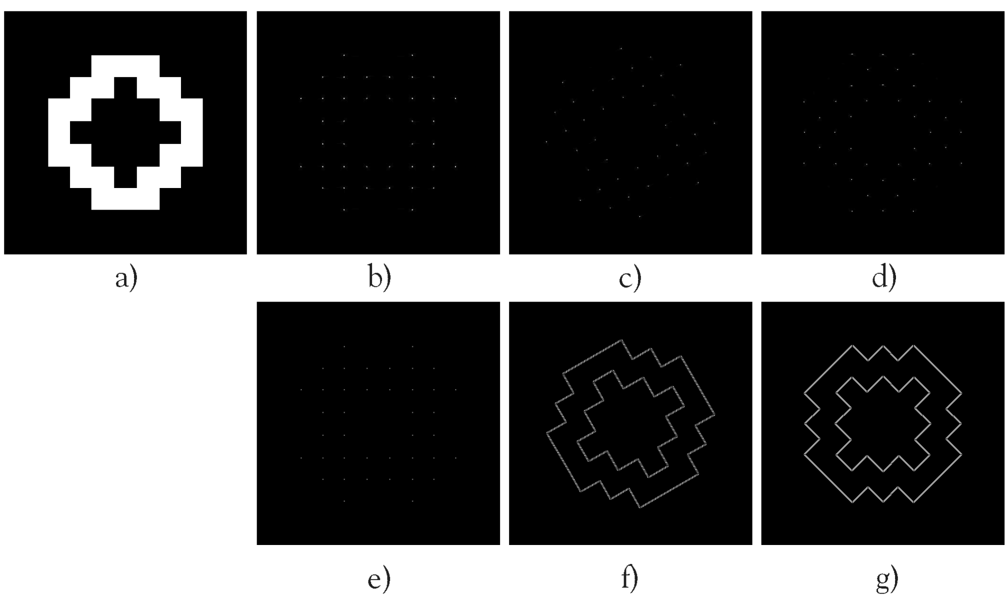

FIGURE 3. a)Binary input scene, and b) to g) numerical simulations for input scene in a). In figures b) to d) the proposed filter with $R_{min} = 10$ pixels was used for azimuthal rotations of 0, 30 and 45 sexagesimal degrees of the input respectively. In figures e) to g) the Haar wavelet transform was used for the same rotation angles of b,c and d).

As it could be noted the proposed method detects with very good performance all the corners of the input scene for the three rotation angles. On the contrary, the Haar wavelet method renders good results only if the input scene is not rotated at all. The corners for rotation angles of 30 and 45 sexagesimal degrees could not be detected with the Haar method.

In order to test the performance of the method on phase modulated scenes, we did numerical simulation with the scene in Fig. 3.a) modulated in phase with $\pi/8$ phase difference. the results for 0, 30 and 45 sexagesimal degrees of azimuthal rotation of the input scene are shown in figs. 4.a) to c) respectively. As it can be noted, the filter works very well for phase modulated scenes.

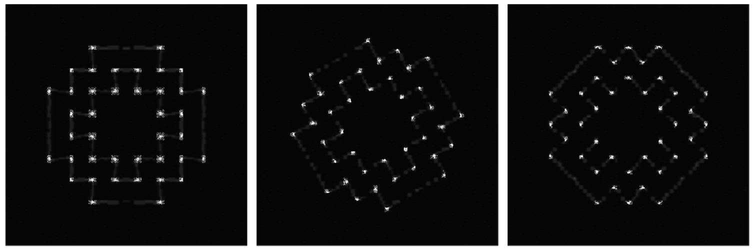

FIGURE 4. Numerical simulations for input scene of Fig. 3.a) modulated in phase. The phase is modulated from 0 to $\pi/8$. In sub-figures a) to c) the proposed filter with $R_{min} = 10$ pixels was used for azimuthal rotations of 0, 30 and 45 sexagesimal degrees of the input respectively.

4. CONCLUSIONS

We have proposed an omnidirectional corner detector. The detector is composed by a spiral phase and a band-pass annular filter. By means of numerical simulations, the performance of the method was studied as a function of the low cutoff frequency of the band-pass filter. Results for a cutoff frequency of $R_{min} = 10$ pixels were presented and the comparison with the traditional Haar wavelet corner detector was made. Also the behavior of the detector with phase input scenes was tested. The obtained results show that the method efficiently detects corners with rotation invariance.

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