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A corner detection technique using unit gradient vectors

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Abstract: This paper presents a novel method for detecting corners in an image irrespective of the contrast. The corner detection method proposed by Kanade, Lucas, and Tomasi (KLT), Ando, and Harris corner detector are among the most widely used algorithms. They are all based on image gradients. Thus, the performances of those conventional approaches depend on the contrast of images. They work well for high-contrasted patterns, but have a difficulty in detecting low-contrasted corners. To overcome the problem, we propose to use unit gradient vectors (UGVs), instead of gradients, because UGVs are known to be a robust image feature and invariant to image contrast.

Keywords: corner detection, pattern recognition, unit gradient vectors.

1 INTRODUCTION

Corner detection is an important task in the field of digital image processing and computer vision. It finds various applications such as image matching, object recognition, motion estimation, etc [1]. Extracting corners can significantly reduce the computation cost in several applications [2]. Motion estimation also gains an advantage from this corner detection. Motion estimation can be performed correctly in an image area that contains a corner. On the other hand, it is difficult to estimate motions in an area that contains a straight edge boundary because of the so-called aperture problem. Thus, the computational cost can be reduced by performing motion estimation only on the image areas where a corner is present. There are several corner detectors that use image gradients. For instance, the corner detection method proposed by Kanade, Lucas, and Tomasi (KLT) utilizes the smaller eigenvalue of the 2×2 gradient covariance matrix defined locally within an image [3], [4]. Next, Ando's method makes use of the two eigenvalues of the 2×2 gradient covariance matrix [5]. The two eigenvalues are combined into a function in a normalized form. Thirdly, the Harris detector also uses the two eigenvalues [6]. Since these existing methods use image gradients, they depend on image contrast. Thus, they operate properly on high-contrasted corners, but it is truly difficult to detect low-contrasted corners.

In this paper, we propose to substitute unit gradient vectors (UGVs) for image gradients because UGVs is a robust image feature and invariant to image contrast.

2 METHODS

2.1 Kanade-Lucas-Tomasi method

Kanade-Lucas-Tomasi (KLT) or gradient method (GM) rests on the assumption that image intensity is constant overtime.

Let $g(x,y)$ be the image intensities at pixel coordinates (x,y). The gradient vector of $g(x,y)$ are approximated by partial derivatives

$$\begin{cases} g_x(x,y) = g(x,y) * k_x \\ g_y(x,y) = g(x,y) * k_y \end{cases} \tag{1}$$

where the symbol $*$ denotes convolution, and k_x and k_y are first-derivative operators in the x and y directions, respectively. The covariance matrix of the two patterns g_x and g_y is expressed by

$$G = \begin{bmatrix} \Sigma {g_x}^2 & \Sigma g_x g_y \\ \Sigma g_x g_y & \Sigma {g_y}^2 \end{bmatrix} \tag{2}$$

where Σ indicates the integration area in a local 2-D space. By applying PCA to the matrix, G, we obtain two eigenvalues λ_1 and λ_2 where $\lambda_1 > \lambda_2 \geq 0$. The corner is detected when two eigenvalue satisfy the condition $\lambda_1 \approx \lambda_2 \geq 0$.

2.2 Ando corner detection

The Ando method can categorize the image field into an omni-direction of the gradient. It can detect corner by using Eq. (3)

$$Q_{EG} = \frac{4\left(\Sigma g_x{}^2 \cdot \Sigma g_y{}^2 - \Sigma g_x g_y{}^2\right)}{\left(\Sigma g_x{}^2 + \Sigma g_y{}^2\right)^2 + \sigma_{EG}{}^4} \quad (3)$$

$\sigma_{EG}{}^4$ is needed to force the denominator does not equal to zero. The value of Q_{EG} is varied from 0 to 1. If it equals or closes to 1, the gradients are omni-directional. On the other hand, if it equal to 0, the gradients are uni-directional.

2.3 Harris corner detection

The Harris corner detector is widely used in digital image processing and computer vision. It can detect both edges and corners by using Eq. (4)

$$H = det\begin{bmatrix} \Sigma g_x{}^2 & \Sigma g_x g_y \\ \Sigma g_x g_y & \Sigma g_y{}^2 \end{bmatrix} - k \cdot \left(trace\begin{bmatrix} \Sigma g_x{}^2 & \Sigma g_x g_y \\ \Sigma g_x g_y & \Sigma g_y{}^2 \end{bmatrix}\right)^2 \quad (4)$$

where k is a constant. It is normally in between 0.04 and 0.06 [11]. The value of H presents the cornerness of the region. If the value is positive, the gradients are omni-directional, while if it is negative, the gradients are one-directional.

2.4 The proposed method

We propose the unit gradient vectors (UGVs) in place of conventional features such as image intensities and gradients, because UGVs are known to be insensitive under the varying illumination [8], [9].

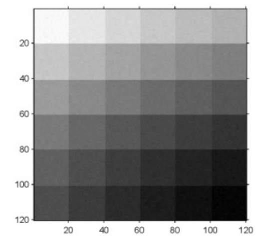
The unit gradient vectors are computed by dividing gradient vectors by their magnitudes:

$$\begin{cases} n_x(x,y) = g_x(x,y)/\sqrt{g_x{}^2(x,y) + g_y{}^2(x,y)} \\ n_y(x,y) = g_y(x,y)/\sqrt{g_x{}^2(x,y) + g_y{}^2(x,y)} \end{cases} \quad (5)$$

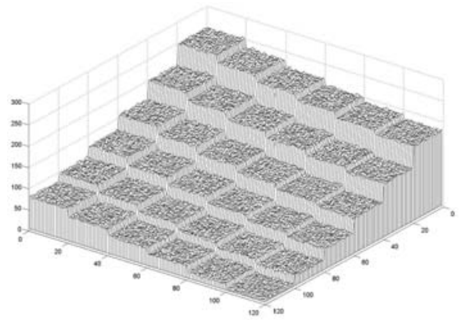
3 RESULTS AND DISCUSSION

For the qualitative evaluation of the corner detection methods, KLT, Ando, Harris corner detector, and the proposed method, the synthetic images are created by generating an 8-bit gray-scale image of size 120 by 120 pixels. The tested image consists of difference 36 intensities levels. It has 25 different contrast corners which are both high and low contrast patterns. The difference of intensity from the top to the bottom of both rows and columns are set from large to small. Zero-noise Gaussian noise is added to test image to generate a noisy image. The signal to noise ratio, SNR, is 40 dB. The size of the block to search the feature is set at 5 by 5 pixels. We search the feature on every single pixel. The tested image is shown in Fig. 1.

We compare the performance of the conventional methods and the proposed method in a pair. We first compared KLT versus the proposed method as show in Fig. 2(a) and 2(b), respectively. The result is scaled from 0 to 1 to simple visualization. The brighter spot respond to the high cornerness on the test image. KLT is high response to the high contrast pattern, in the upper-left of the image, but almost miss the low contrast pattern, in the lower-right of the image as show in Fig. 2(a). The proposed method is high response to the entire corner pattern as show in Fig. 2(b).

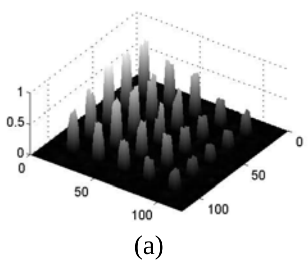


(a)

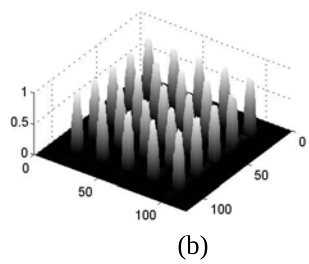


(b)

Fig. 1. (a) A mildly noisy test image. (b) The test image plotted in 3D.



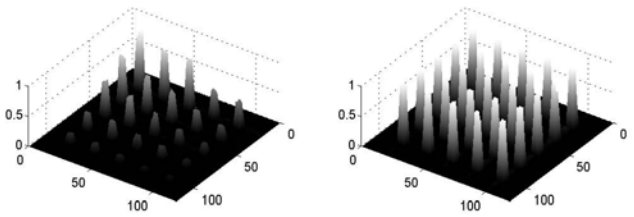
(a)



(b)

Fig. 2. Responses to corners by (a) the KLT method and (b) the proposed method.

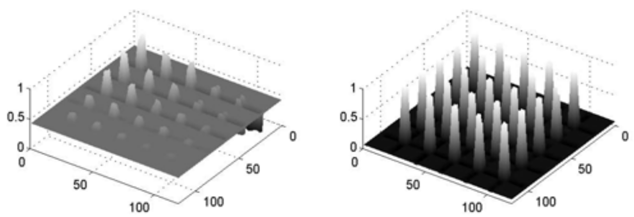
Secondly, we compared the Ando corner detection with the proposed method as show in Fig. 3. The corners are selected by using Ando method with σ = 900 as shown in Fig. 3(a). The proposed method also uses the same value of σ which used in Ando method but proposed method shows the outer performance that has high response on the low contrast area which Ando has low response.



(a) (b)

Fig. 3. Responses to corners by (a) the Ando method, (b) the proposed method.

Next, Harris corner detector is compared with proposed method. The corner is selected by using the Harris corner detector with k = 0.04 as show in Fig. 4(a). Harris can detect both corner and edge in the same time. The white and black pixels respond to the corner and edge, respectively while the gray pixels are shown the flat area. Even it can detect all difference patterns, i.e., corner, edge, and flat area, in the entire image, it almost miss the detection in the low contrast corner. Fig. 4(b) shows the response of the proposed method. It can detect all different patterns especially, also detect the low contrast corner.



(a) (b)

Fig. 4. Responses to corners by (a) the Harris corner detector and (b) the proposed method.

4 CONCLUSION

This paper presents a comparative study between the popular feature detection methods such as KLT, Ando, and Harris corner detectors, and the proposed method. We introduce the unit gradient vectors in place of conventional image information as gradient. We have shown that the proposed method can detect corners regardless of their contrast. This will lead to stable corner detection under difficult conditions such as irregular illuminations and poor lighting.

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