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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (18): 4588-4592, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.4588.4592

Model Research of Location and Inspection for Circular Objects and its Application

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Abstract: Many techniques for locating circular objects in images have been presented. However, it's still a challenge to extract circles for images coincidently with weak contrast in strong complex backgrounds. In this study, we propose a computational method using global symmetry, which can robustly locate circles in images. Furthermore, it can independently inspect circular objects with simple patterns. Our method aims at designing a symmetry measure based on distance weight, phase weight and intensity weight. Then based on the measure, a systemic approach is given to inspect arbitrary circular objects under uncertain situations in virtue of an invariant content-based descriptor. The experimental results show the presented approach to be promising.

Key words: Location, inspection, image processing, symmetry measure, distance weight, phase weight, Fourier-Mellin transform

INTRODUCTION

People possess a natural visual perception mechanism based on symmetry detection (Ban *et al.*, 2006; Dakin and Herbert, 1998), as a result, when we look at an object with bad quality such as broken edges or contaminated surfaces, we can easily perceive the abnormality without seeing a regular one. Accumulated evidences have indicated that symmetry detection appears to have great potentials for computer-vision-based applications (Beck *et al.*, 2005; Gong *et al.*, 2007; Lucchese and Cortelazzo, 2000).

Symmetry is defined by some characteristic fixity under a class of Euclidian transformations (Beck *et al.*, 2005; Kovesi, 1995). As for image processing, definition and detection for symmetry becomes more complex due to the difficulty in selecting definite features. The existing work includes methods based on frequent features by using wavelets (Kovesi, 1995) and Fourier transforms (Lucchese and Cortelazzo, 2000; Yip, 2007). And, based on spatial features includes those of using gradients and local points (Loy and Zelinsky, 2003; Reisfeld *et al.*,1990; Labonte *et al.*, 1995). Also, global symmetry is calculated based on the symmetry of energy, topology, biological mechanisms or other features (Dakin and Herbert, 1998; Gong *et al.*, 2007; Huebner, 2007; Zavidovique and Gesu, 2007; Milner *et al.*, 2007).

Although, much attention has been paid on detecting symmetry, few efforts have been put to implement symmetry into real vision-based applications. Moreover, it is still a challenging task to extract objects under cluttered backgrounds, especially for objects with weak contrast and varying illuminations. For example, it is well known that there are many classical methods to find circles in images, such as moments, Hough transforms, active contours, least-square methods (Ballard, 1981; Cao *et al.*, 2006), however, these methods completely fail when objects' gradients are weaker than those of their backgrounds.

In this study, we give a computational method to inspect circular objects using global symmetry. A symmetry measure is designed based on gradients and distances of interest. It is suitable to inspect arbitrary.

PROPOSED SYMMETRY MEASURE

For an image I (x, y) of size M×N, the gradient of a point $\vec{P_{ij}}$ is denoted by $\nabla P_{ij} = (\nabla x_i, \nabla y_j)$ and the direction of $\vec{P_{ij}}$ by:

$$\theta_{ij} = \arctan(\frac{\nabla y_j}{\nabla x_i})$$

Let $P_{i_c j_c}$ denote the middle point of the any possible symmetric pair P_{ij} and $P_{i'j'}$, α_{ij} the angle of the pair.

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Following Reisfeld *et al.* (1990), the set of P_{icjc} is given as:

$$M_c = \{(i_c, j_c) \left| i_c = \frac{i+i'}{2}, j_c = \frac{j+j'}{2}\right.\} \quad (1)$$

A vector measuring for intensity at every point P_{ij} is given as:

$$r_{ij} = \|\Delta P_{ij}\| \quad (2)$$

where $\|\nabla P_{ij}\|$ is normalized between 0 and 1. It is used for calculating the intensity weight function.

Distance weight: Let $U = (u_1, u_2, \ldots, u_n)$ designate the scale vector of all interest distances in an object, n is the number of distance scales. u_{max} is the maximal interest distance. For circular objects, u_i is the diameter of the i^{th} included circle. A distance weight function $D_{\sigma i}$ is defined as:

$$D_{\sigma_i} = e^{\frac{-(d_{pair}-u_i)^2}{2\sigma_i^2}} \quad (3)$$

Where:

$$d_{pair} = \sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}$$

is the distance between the two candidate symmetrical points P_{ij} and $P_{i'j'}$... $D\sigma_L$ in the form of a standard Gaussian deviation, is the continuous distance weight function with n extrema, here σ_i confines the bandwidth of $D_{\sigma i}$ at distance u_i.

Phase weight: A phase weight function $\Delta\theta$ is defined as:

$$\Delta\theta = \left|\cos(\theta_{ij} + \theta_{i'j'} - 2\alpha_{ij})\right| \quad (4)$$

where, θ_{ij} and $\theta_{i'j'}$ are the directions at the candidate symmetrical pair points P_{ij} and $P_{i'j'}$ respectively, α_{ij} is the slope angle of the straight line passing through them.

For simplification, all angles are normalized into the range of $[0, \pi]$. Thus, $(\theta_{ij}+\theta_{i'j'}-2\alpha_{ij})$ equals to 0 for two points of ideal mirror symmetry and $\theta_{ij}+\theta_{i'j'}-2\alpha_{ij}$ equals to π for two points of ideal bilateral symmetry. That is, when the two points are more symmetrical, $\Delta\theta$ is much closer to 1.

Intensity weight: An intensity weight function ΔR is defined as:

$$\Delta R = r' \cdot e^{\frac{-(r_{ij}-r_{i'j'})^2}{\sigma^2}} \quad (5)$$

Where:

$$\hat{r} = \frac{r_{ij} + r_{i'j'}}{2}, r' = \frac{1}{\hat{r}} \cdot \hat{r}^{\frac{1}{\beta}}$$

and:

$$\beta = \frac{f_{max}(x,y) - f_{min}(x,y)}{L}$$

is an intensity weight factor that acts on balancing objects' contrast and L is the gray level of the image, f_{max} (x, y) and f_{min} (x, y) is the respective maximal and minimal gray value of the image.

Symmetry measure: Finally, based on the above three weight functions, a symmetry measure on the set M_c is given as:

$$S_\sigma(i_c, j_c) = \sum_{(i_c, j_c)\in M_c} (D_{\sigma_i} \cdot \Delta\theta \cdot \Delta R) \quad (6)$$

It describes the symmetries of intensities, structures and directions. The extreme point of (6) means the point with the maximal symmetric measure. So, it is center for circular objects. In cluttered backgrounds, the noise can be efficiently filtered out since it is irregular and non-symmetric.

Main contribution: The symmetry measure described in the study was inspired by the previous work of Reisfeld *et al.* (1990). However, we extend the algorithm in the following aspects. Firstly, by extending the distance weight function with different scales of interest distances, a symmetry measure of global or local can be computed. In the previous work, Reisfeld *et al.* (1990) detected only local symmetry. Secondly, a much simpler phase weight function is given for the detection of bilateral and mirror symmetry of all directions. It's more efficient in calculating the symmetry measure than the weight in (Kovesi, 1995). Thirdly, we add a new intensity weight function for balancing the symmetric weak edges. Finally, we apply the proposed method into real industrial inspecting systems.

CIRCULAR OBJECTS' INSPECTION

Circular objects location: In the study, the maximal scale u_{max} is set as the diameter of the object. The symmetry scale vector $U = (u_1, u_2, \ldots, u_n)$ is obtained by the global optimization algorithm (Gofman and Kiryati, 1996).

In order to get a full-scale information for an object within its maximal interest distance u_{max}, the deviation σ_i is usually set to guarantee $D_{\sigma i} > 0$.

Then, from (6), the center of a circular object corresponds to the maximum in the corresponding symmetry map $S\sigma\ (i_c, j_c)$.

Similarities for measuring objects: Usually, it's enough to take a small region of interest (ROI) around the maximum in the symmetry map to calculate the similarity measure (Sm). The size ofROI is $R_{roi} = 0.1u_{max} \sim U_{MAX}$.

A simple way to compare the similarity of two ROIs, based on their feature vectors γ_τ and γ_{cp}, is given by the normalized scalar product as:

$$SM = \frac{|\gamma_\tau \cdot \gamma_{cp}|}{\|\gamma_\tau\| \|\gamma_{cp}\|} \tag{7}$$

where, γ_τ and γ_{cp} are the vectors of intensity. The defective objects can be classified out when $SM < SM_{thresh}$, where SM_{thresh} is the threshold. It is a statistics of a series of samples, as:

$$SM_{thresh} = SM_{bad} + \frac{SM_{good} - SM_{bad}}{2} \tag{8}$$

where, $SM_{bad,}$ SM_{good} are the average similarity measure of defective samples, regular samples, respectively.

Certainly, SM can be got based on some invariant content-based descriptors (Milanese *et al.*, 1998; Muller *et al.*, 2001; Xin *et al.*, 2007). In the study, Fourier-Mellin transform (Cao *et al.*, 2006) is used to describe the arbitrary separated circular object.

EXPERIMENTAL RESULTS

The method is tested in a real application system for inspecting medical lids. The defects of lids include malformed shapes, broken edges, stained surfaces and so on. Sample lids are shown in Fig. 1. The distance weight functions in (3) are constructed by taking the lids' three main symmetric circular patterns and R_{roi} = 30. The

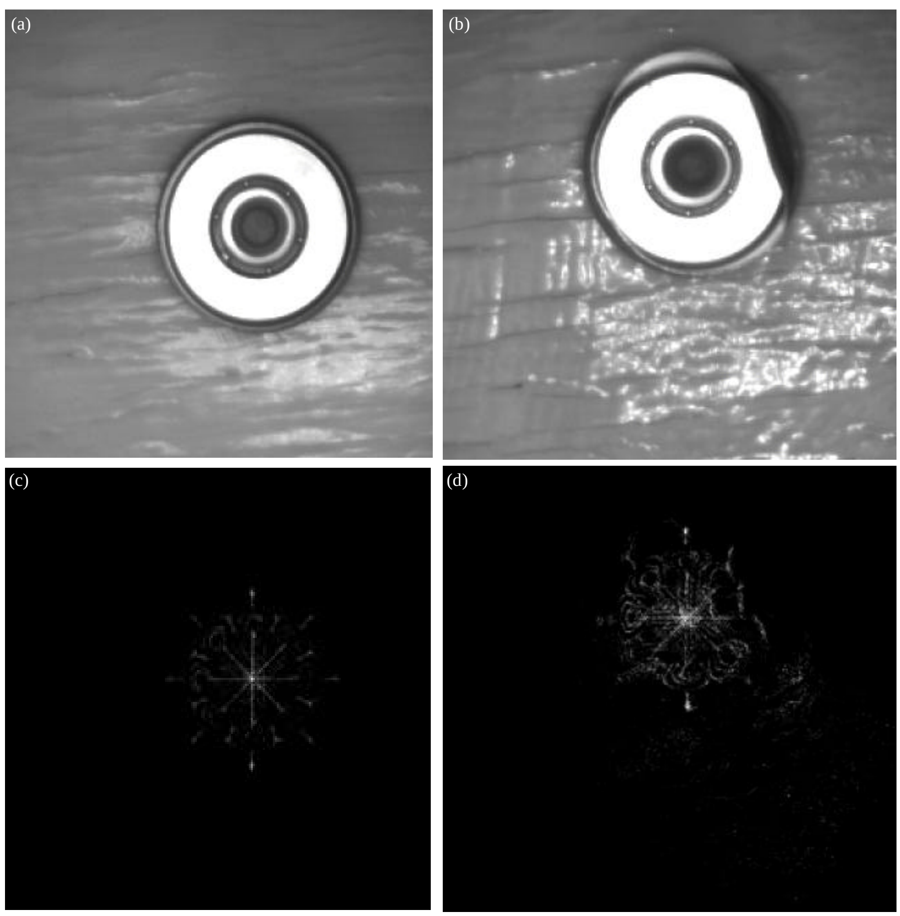

Fig. 1(a-d): (a) A regular lid image, (b) a defective lid image, (c)the symmetry map of (a) and (d) the symmetry map of (b)

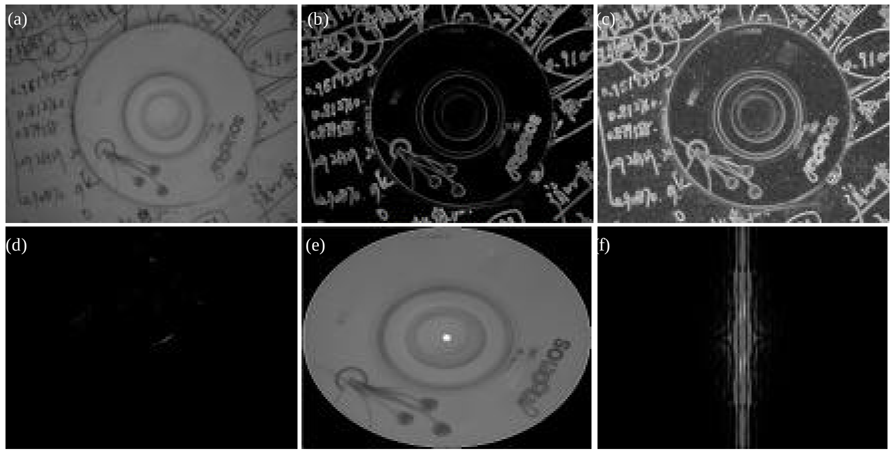

Fig. 2(a-f): (a) An original CD image, (b) The sobel gradient map of (a), (c) Gradient map of (a) with balanced intensities using (5), (d) The symmetry map of (c), (e) The separated CD by the proposed method, (f) the Fourier-Mellin transform of (e)

Table 1: Inspecting results of circular objects

Lids	Total	Passed	Filtered out	Precision(%)
Regular	80,000	78,936	1,064	98.92
Defective	20,000	12	19,988	
Regular	80,000	78,936	1,064	98.92
Defective	20,000	12	19,988	

referenced vector γ_τ is obtained by averaging the vectors of ROIs obtained from 500 regular images. A total number of 100,000 sample lids are tested and the result is shown in Table 1.

The other test is given for inspecting Compact Discs (CDs) which contain non-symmetric patterns, with weak contrasts under a strongly cluttered background, as shown in Fig. 2. For speed, only the maximal scale is set in the distance weight function for the purpose of locating objects. The other parameters for calculating the symmetric map are set similar to the above experiment.

In Fig. 2a, the edge of the disc (Fig. 2b) is very weak compared to the strong cluttered background. Only the symmetric weak edges are strengthened as in Fig. 2c. Based on the gradient map in Fig. 2b, classical methods of finding circles failed (Ballard, 1981; Cao *et al*., 2006). However, the proposed method gives the well separated object according to the symmetric map in Fig. 2d. Then Fourier-Mellin transform (Cao *et al*., 2006) is used for representing the separated CD. The total test number is 1000 and the inspecting result is shown in Table 1.

CONCLUSION

In this study, a systematic approach for robustly inspecting circular objects is given. The proposed symmetry measure, on the one hand, can directly be used to inspect circular objects with symmetric patterns. On the other hand, it can locate arbitrary circular objects under uncertain backgrounds. In the latter case, after the object is located, a content-based descriptor is used to achieve the inspecting task.

ACKNOULEDGMENTS

This study was supported by the Fundamental Research Funds for the Central Universities (YX2011-16), Beijing Higher Education Young Elite Teacher Project (BJQNYC201333) and the National Natural Science Foundation of China(Grant No. 61179034).

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