

2012 AASRI Conference on Modelling, Identification and Control

## Visual Inspection for Circular Objects Based on Global Symmetry

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### Abstract

The research is aimed to accomplish an automatic visual inspection system for circular objects using cameras and image processing technique. The main concern of the paper is on the pattern analysis of circular objects based on image analysis. First, the authors propose a computational method using global symmetry to locate objects before the further inspection process. It aims at designing a symmetry measure based on distance weight, phase weight and intensity weight. Such measure can be used to locate centers of circles, even for those with weak contrast under uncertain complex backgrounds. Then based on the measure, similarities of arbitrary circular objects are given and tested. The experimental results for the proposed approach are promising.

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Selection and/or peer review under responsibility of American Applied Science Research Institute

*Keywords:* visual inspection; global symmetry; circular objects; finding circles; Fourier-Mellin transform

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### 1. Introduction

When we look at an object with bad quality such as broken edges or contaminated surfaces, we can effortlessly perceive the abnormality without seeing a regular one. People possess a natural visual perception mechanism based on symmetry detection [1, 2]. Accumulated evidences have indicated that symmetry detection appears to have great potentials for computer-vision-based applications [3, 4, 5].

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Mathematically, symmetry is defined by some characteristic fixity under a class of Euclidian transformations [3, 6]. 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 [6] and Fourier transforms [5, 7]. And, based on spatial features includes those of using gradients and local points [8, 9, 10]. Also, global symmetry is calculated based on the symmetry of energy, topology, biological mechanisms or other features [2, 4, 11, 12, 13].

However, 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 [14, 15]. However, these methods completely fail when objects' gradients are weaker than those of their backgrounds.

In this paper, we propose 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 circular objects robustly, even for those with weak contrast under strong cluttered backgrounds. The method is tested in several experiments and has been successfully applied into real vision-based inspecting systems.

## 2. The proposed symmetry measure

For an image  $I(x, y)$  of size  $M \times N$ , the gradient of a point  $\overline{P}_{ij}$  is denoted by  $\nabla P_{ij} = (\nabla x_i, \nabla y_j)$  and the direction of  $\overline{P}_{ij}$  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  $P_{i' j'}$ ,  $\alpha_{ij}$  the angle of the pair. Following Reisfeld [9], the set of  $P_{i_c j_c}$  is given as

$$M_c = \{(i_c, j_c) \mid i_c = \frac{i+i'}{2}, j_c = \frac{j+j'}{2}\} \quad (1)$$

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

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

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

### 2.1. Distance weight

Let  $U = (u_1, u_2, \dots, u_n)$  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  $i^{\text{th}}$  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  $P_{i'j'}$ .  $D_{\sigma_i}$ , in the form of a standard Gaussian deviation, is the continuous distance weight function with  $n$  extrema, here  $\sigma_i$  confines the bandwidth of  $D_{\sigma_i}$  at distance  $u_i$ .

## 2.2. 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  $\theta_{ij}$  and  $\theta_{i'j'}$  are the directions at the candidate symmetrical pair points  $P_{ij}$  and  $P_{i'j'}$ , respectively,  $\alpha_{ij}$  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  $\pi$  for two points of ideal bilateral symmetry. That is, when the two points are more symmetrical,  $\Delta\theta$  is much closer to 1.

## 2.3. Intensity weight

An intensity weight function  $\Delta R$  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.

## 2.4. 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.

### 2.5. Main contribution

The symmetry measure described in the paper was inspired by the previous work of Reisfeld [6]. 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. Whereas Reisfeld detects 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 [6]. 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.

## 3. Inspection for circular objects

### 3.1. Circular objects location

In the paper, the maximal scale  $u_{\max}$  is set as the diameter of the object. The symmetry scale vector  $U = (u_1, u_2, \dots, u_n)$  is obtained by the algorithm of global optimization in [16].

In order to get a full-scale information for an object within its maximal interest distance  $u_{\max}$ , the deviation  $\sigma_i$  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  $S_{\sigma}(i_c, j_c)$ .

### 3.2. 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 of  $ROI$  is  $R_{roi} = 0.1u_{\max} \sim u_{\max}$ .

A simple way to compare the similarity of two  $ROIs$ , based on their feature vectors  $\gamma_{\tau}$  and  $\gamma_{cp}$ , is given by the normalized scalar product as

$$SM = \frac{|\gamma_{\tau} \cdot \gamma_{cp}|}{\|\gamma_{\tau}\| \|\gamma_{cp}\|} \quad (7)$$

where  $\gamma_{\tau}$  and  $\gamma_{cp}$  are the vectors of intensity. The defective objects can be classified out when

$$SM < SM_{thresh} \quad (8)$$

where  $SM_{thresh}$  is the threshold. It is a statistics of a series of samples, as

$$SM_{thresh} = SM_{bad} + \frac{SM_{good} - SM_{bad}}{2} \quad (9)$$

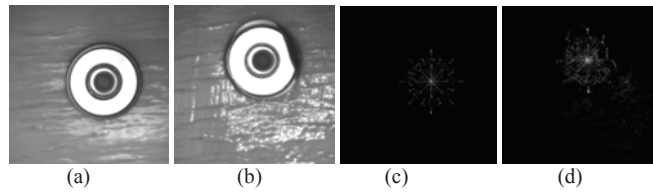


Fig. 1. (a) A regular lid image, (b) a defective lid image, (c) the symmetry map of (a), (d) the symmetry map of (b).

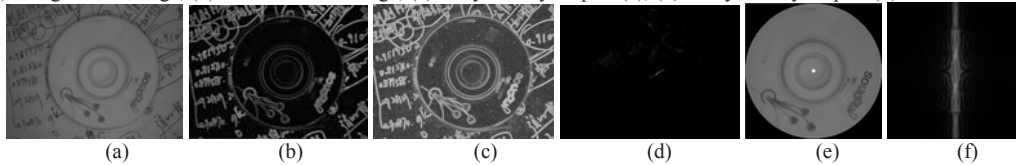


Fig. 2. (a) An original CD image, (b) the Sobel gradient map of (a), (c) the gradient map of (a) with balanced intensities using (5), (d) the symmetry map of (c), (e) the separated CD by the proposed method, (f) the Fourier-Mellin transform of (e).

Table 1. The inspecting results of circular objects

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

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

Certainly,  $SM$  can be got based on some invariant content-based descriptors [17, 18, 19]. In the paper, Fourier-Mellin transform [15] is used to describe the arbitrary separated circular object.

#### 4. 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 referenced vector  $\gamma_r$  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.2 (a), the edge of the disc (Fig.2(b)) is very weak compared to the strong cluttered background. Only the symmetric weak edges are strengthened as in Fig.3(c). Based on the gradient map in Fig.2 (b), classical methods of finding circles failed [14, 15]. However, the proposed method gives the well separated object according to the symmetric map in Fig.2 (d). Then Fourier-Mellin transform [15] is used for representing the separated CD. The total test number is 1000 and the inspecting result is shown in Table 1.

## 5. Conclusion

In this paper, 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.

## Acknowledgements

This work was supported by the Fundamental Research Funds for the Central Universities (YX2010-13, YX2011-16), the National Natural Science Foundation of China (Grant No. 61179034)

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