Using Convex Hull for Fast and Accurate Ellipse Detection

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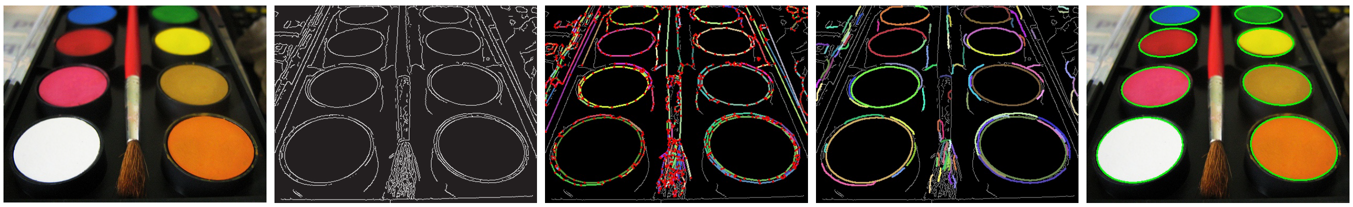

Figure 1: The pipeline of the proposed ellipse detection method. From left to right: input image, edge map, line segment approximation, extracted arcs and detected ellipses.

ABSTRACT

We present a novel method for fast and accurate ellipse detection based on an efficient arc grouping strategy. We first extract edges from the input image, and then obtain smooth arcs by recognizing sharp turns and inflexion points. To speed up ellipse generation, we group arcs by three intuitive yet more efficient rules, followed by a validation and a more distinctive cluster scheme to further improve the accuracy. Our approach achieves promising results on both synthetic and three real-world datasets.

CCS CONCEPTS

• **Computing methodologies** → **Shape detection**.

KEYWORDS

Ellipse detection, Edge detection, Edge following

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1 INTRODUCTION

Ellipses appear commonly in nature and daily life, thus ellipse detection has numerous applications in various fields, such as industrial component inspection, satellite location, robot grasping and so on. However, due to the disturbance of noise, occlusion, clutter and lighting, fast and accurate ellipse detection is still challenging.

Many ellipse detectors have been proposed in the past few decades. For instance, Hough transform [Hough 1962] takes a voting scheme and the peak in the parameter space is picked out as an ellipse, but this method is very time consuming and needs extensive storage. Edge-following-based methods utilize continuous arcs rather than edge points to speed up detection, but complicate arc grouping strategies with sensitive differential calculation are usually adopted [Prasad et al. 2012].

In this work, we propose a novel ellipse detection method with a more intuitive yet efficient arc grouping strategy based on convex hull computation. Different from traditional edge-following methods, the convex hull not only characterises the convexity of arcs but also avoids the differential calculation. Besides, we present a more distinctive cluster formula to suppress duplicated ellipses and pick out salient ones.

2 OUR APPROACH

Given an image, our detection pipeline consists of the following steps (see Fig. 1 for an illustration).

(1) Edge detection. We first use the Canny detector [Canny 1986] to extract the edge map as shown in Fig. 1(b). Then the 8-connected pixels are checked to obtain continuous edge curves.

(2) Arc extraction. To improve the fitting accuracy, we further extract elliptical arcs from edge curves based on the fact that ellipses have continuous curvature. To this end, we adopt the Ramer-Douglas-Peucker (RDP) algorithm [Hershberger and Snoeyink 1992] to approximate edges by a series of line segments as illustrated in Fig. 1(c). Then arcs are obtained through the identification of sharp turns and inflexion points (see Fig. 2). After this process, we use the minimum area bounding box to remove line segments whose width-height ratio is greater than 20 and delete short arcs to speed up detection.

(3) Arc grouping. We group co-elliptic arcs together by three intuitive yet efficient rules to avoid frequently calling fitting algorithms for each arc. Two arcs are co-elliptic if they satisfy

• *Minor length difference*: normally short arcs come from small ellipses, while long arcs tend to come from larger ones. Hence the

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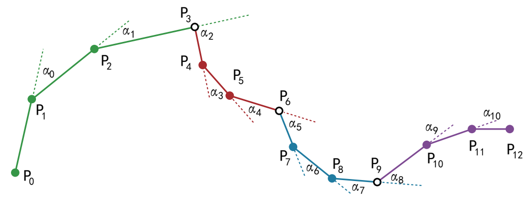

Figure 2: Recognition of sharp turns and inflexion points. If $(\overrightarrow{P_{i-1}P_i})_1 \cdot (\overrightarrow{P_iP_{i+1}})_1 \geq \cos 46^\circ$ or $((\overrightarrow{P_{i-2}P_{i-1}})_1 \times (\overrightarrow{P_{i-1}P_i})_1) \cdot ((\overrightarrow{P_{i-1}P_i})_1 \times (\overrightarrow{P_iP_{i+1}})_1) < 0$, then P_i is a sharp turn or an inflexion point, where $(\overrightarrow{P_iP_{i+1}})_1$ is the unit vector of the line segment P_iP_{i+1}. Thus P_3 is a sharp turn while P_6 and P_9 are inflexion points.

length of co-elliptic arcs shouldn't differ too much;
• *Small arc distance*: since the size of ellipses is finite, two arcs far from each other are unlikely come from the same ellipse. We evaluate that by the comparison of arc length over midpoint distance;
• *Formation of convex hull*: from the point of convexity, the link of endpoints and midpoints of two arcs ought to be a convex hull. See Fig.3 as an example.

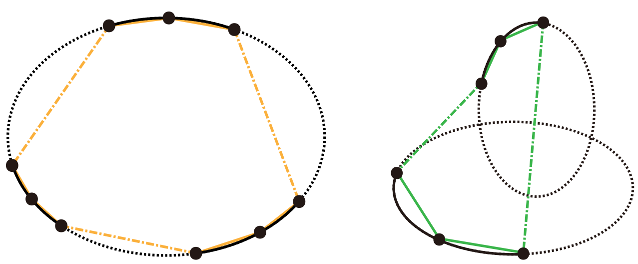

Figure 3: Arc grouping by convex hulls. The left arcs satisfy the convex hull constraint, while the right arcs do not.

(4) Validation and clustering. Co-elliptic arcs are fit to obtain candidate ellipses. To suppress false ellipses, a salient score of the candidate ellipse Ell_i is computed by

$$score(Ell_i) = \frac{\sum_{p \in P_i} near(p, Ell_i)}{|P_i|},$$

where P_i is the point set fitting Ell_i, and $near(p, Ell_i)$ is an indicator function defined as $\mathbb{1}\{dist(p, Ell_i) < 1.5\}$. Moreover, we devise a similarity metric between two ellipses Ell_i and Ell_j to remove duplicate ellipses:

$$ES(Ell_i, Ell_j) = (\sum_{\lambda \in \Lambda} k_\lambda \cdot (\lambda_i - \lambda_j)^2)^{\frac{1}{2}}$$

Here $\Lambda = (a, b, x_c, y_c, \theta)$ is the elliptic parameter, and k_λ is set to one except for θ where $k_\theta = \min(\frac{a_i - b_i}{a_i + b_i}, \frac{a_j - b_j}{a_j + b_j})$. This strategy effectively eliminates the influence of rotational symmetry of circles.

3 EXPERIMENT RESULTS

We compare our method with two state-of-the-art work ([Jia et al. 2017] & [Lu et al. 2019]) on three real-world datasets and one synthetic dataset containing 4-24 occluded ellipses. Fig.4 shows that the method Jia takes relatively low running time but with the severe sacrifice of F-1 score especially when the number of occluded ellipses increases. The method Lu consumes much more time although it has been narrowed down by a factor. In contrast, our method exhibits better performance in both F-1 score and running time for all datasets. An illustration is presented in Fig.5.

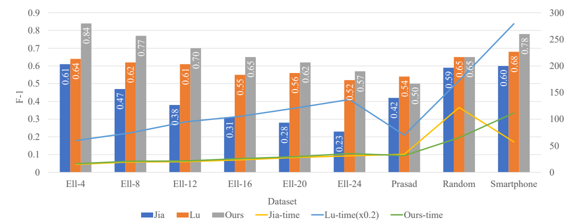

Figure 4: F-1 score and time of different methods.

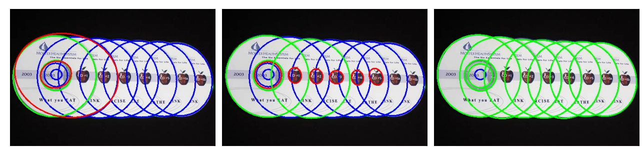

Figure 5: From left to right are comparison results of Jia, Lu and Ours. True ellipses, false ellipses and ground truths are indicated by green, red and blue colors, respectively.

4 CONCLUSION AND FUTURE WORK

We propose an efficient ellipse detector using convex hull based on the edge-following framework, which achieves fast and accurate performance on four public datasets. In the future, we plan to make a deeper analysis and more comparison with previous work, and apply our method to practical tasks such as robot grasping.

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