Circle Detection by Arc-support Line Segments

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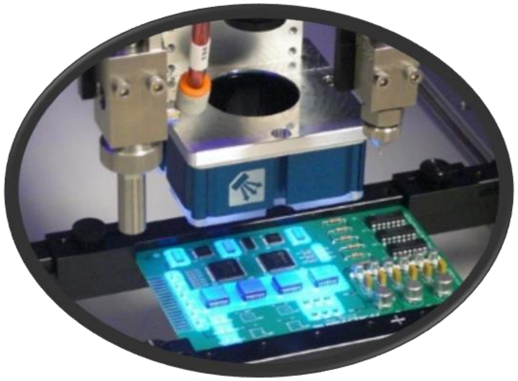
Contents

- Background introduction
- Arc-support line segment extraction
- Paired line segments analysis
- Circle candidate generation and validation
- Experimental results
- Summary

Background introduction

- Main Applications



- Shape recognition
- Object localization and measurement
- Image segmentation
- Edge contour modelling
- ……

Background introduction

- Current methods

1) Hough Transform (HT) based methods
    - Circle Hough Transform (CHT)
    - Randomized Hough Transform (RHT)

2) Random Sample Consensus (RANSAC) based methods
    - Random Circle Detection (RCD)

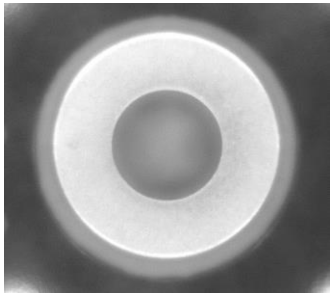
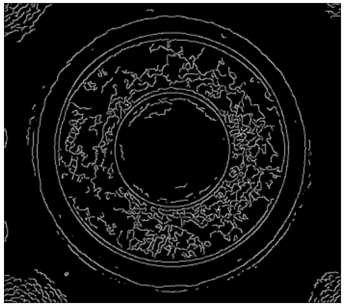
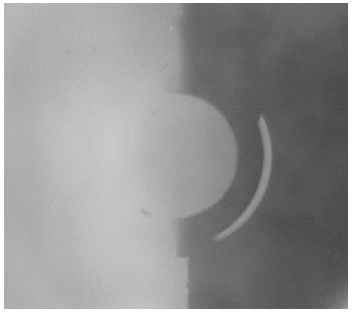
3) Line Segments Approximating based methods
    - Truc Le el. al [1] method

[1] Truc Le and Ye Duan, Circle detection on images by line segment and circle completeness, *IEEE ICIP*, 2016, pp. 3648–3652.

Background introduction

➢ Challenges

- ➢ The existence of substantial noises, edge blurring and corruption in industrial environment
- ➢ Brightness and shadow
- ➢ Object occlusion
- ➢ The circles with different structures. E.g. concentric, overlapping and discontinuous.
- ➢ The requirements of high location accuracy and robustness in complex backgrounds


Background introduction

- Goal
  - Propose an effective, high-accuracy and robust circle detector
  - Achieve very low error recognition rate which guarantees the detection system' s stability and security.
  - Be capable to deal with the disturbances of complex environment

Contents

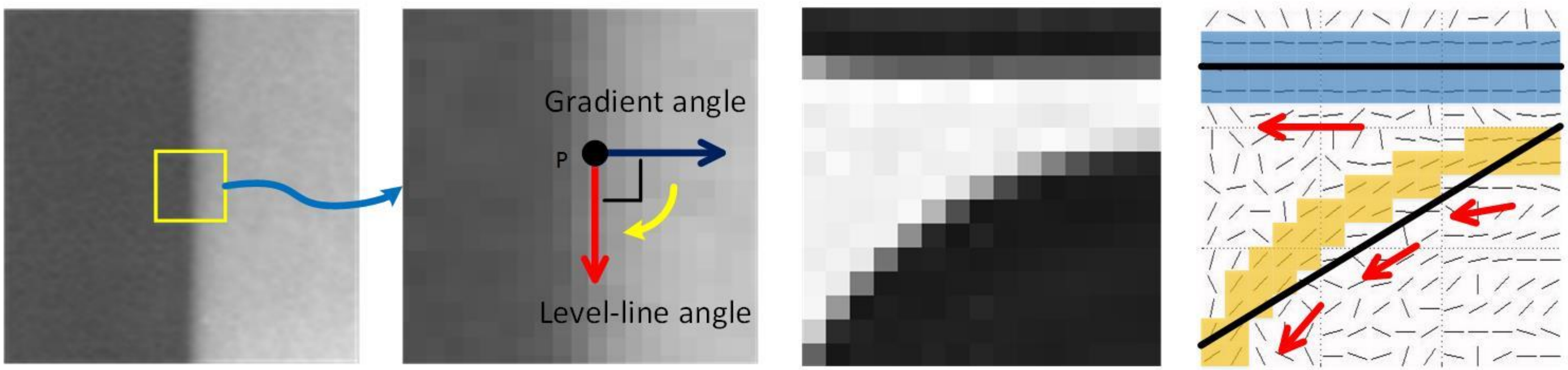
Arc-support line segment extraction

- Gradient angle
- Level-line angle

  Obtained by rotating gradient angle 90° clockwise
- Line segment types:

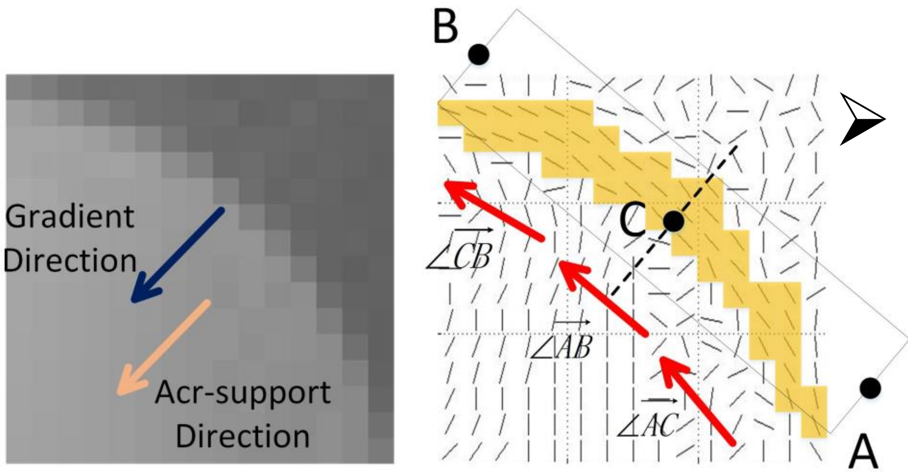
  1) Line segment that derives from high straight edge

  2) Arc-support line segment



(a) (b) (c)

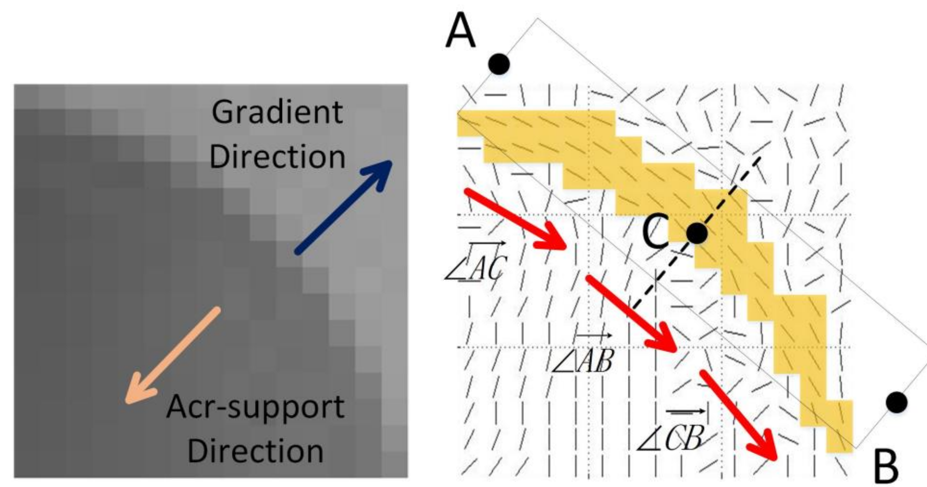
Arc-support line segment extraction



(a) (b)

- Direction estimation
  1) PCA
  2) $arctan\left(\frac{\sum_{p_i \in Region} \sin(level\text{−}line\ angle(p_i))}{\sum_{p_i \in Region} \cos(level\text{−}line\ angle(p_i))}\right)$

3) Denote main direction as $\angle\overrightarrow{AB}$ and the directions of two sub-regions as $\angle\overrightarrow{AC}$, $\angle\overrightarrow{CB}$



(c) (d)

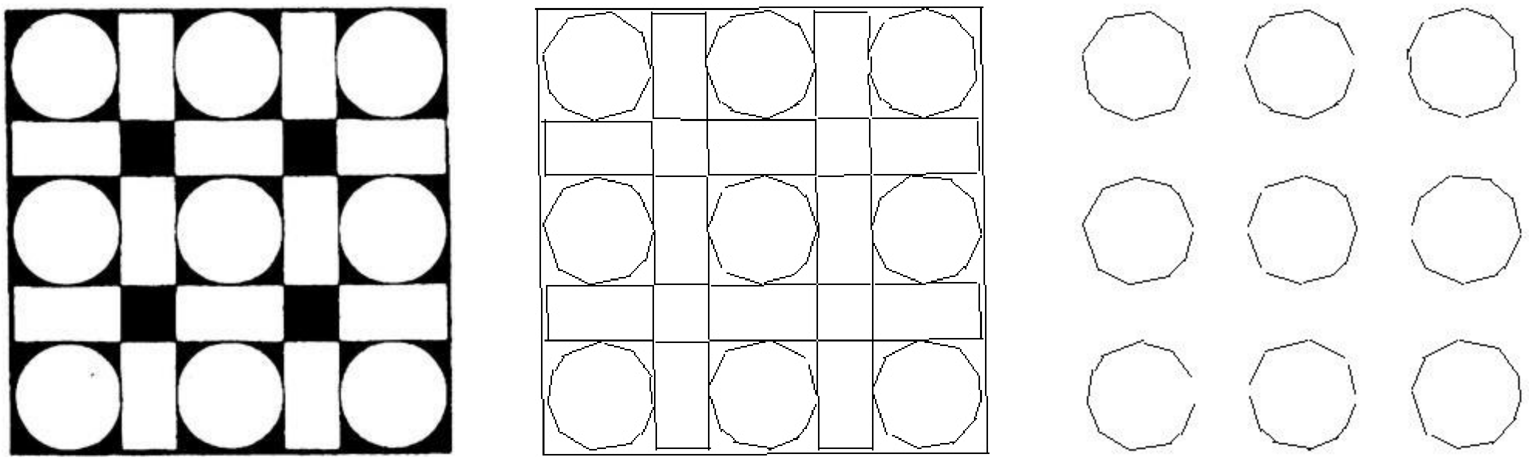
Arc-support line segment extraction

- Conditions
  1) $\angle\overrightarrow{AC}$, $\angle\overrightarrow{AB}$, $\angle\overrightarrow{BC}$ should change in either the clockwise or anticlockwise.
  2) Angle intervals of $\{\angle\overrightarrow{AC}, \angle\overrightarrow{AB}\}$ and $\{\angle\overrightarrow{AB}, \angle\overrightarrow{BC}\}$ should be larger than T_{ai}

- Properties of arc-support LS
  1) Polarity is positive if overall gradient direction is same as arc-support direction. Otherwise it is negative.
  2) All the arc-support LSs derive from curve edge

Arc-support line segment extraction

➢ Results



(a) (b) (c)

Results of line segment extraction. (a) origin image. (b) 146 LSs are extracted by LSD [2]. (c) 92 arc-support LSs are extracted by proposed method

[2] Grompone v G R, Jakubowicz J, Morel J M, et al. LSD: a fast line segment detector with a false detection control.[J]. *IEEE TPAMI*, 2010, 32(4):722–732.

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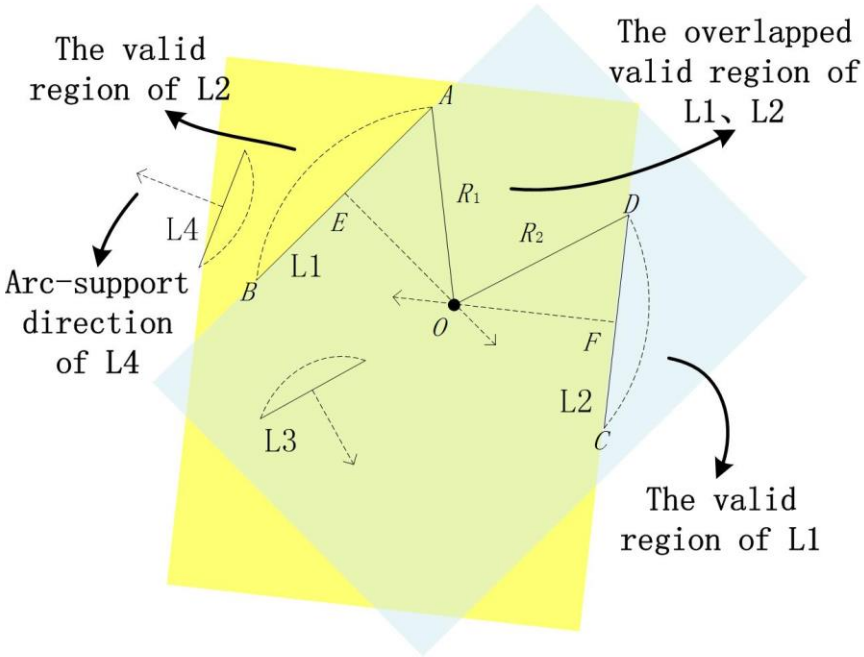
Paired line segments analysis

- Polarity analysis

  In general, especially in industry, the extracted arc-support LSs of an object share the same polarity

- Region restriction

$$\begin{cases} \overrightarrow{AC} \cdot \overrightarrow{ARC_{L1}} > \rho_d \\ \overrightarrow{AD} \cdot \overrightarrow{ARC_{L1}} > \rho_d \\ \overrightarrow{CA} \cdot \overrightarrow{ARC_{L2}} > \rho_d \\ \overrightarrow{CB} \cdot \overrightarrow{ARC_{L2}} > \rho_d \end{cases}$$



Paired line segments analysis

- Radii & inliers criteria
  1) The radii (R_1 and R_2) should be within a radial distance tolerance ϵ_{rd}

  2) The percentage of valid inliers should be larger than γ. (The inliers that make up L_1 and L_2 are valid if they satisfy distance tolerance ϵ_{id} and normal tolerance α)

The set of valid pair → Initial circle set

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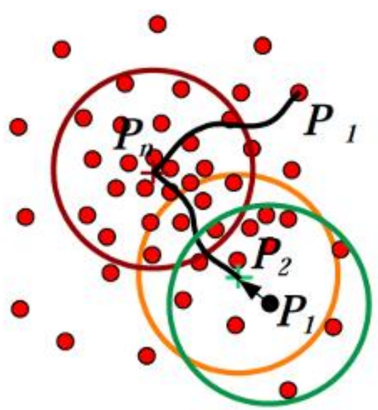
Circle candidate generation and validation

- Circle candidate generation

 1) Due to there existing many duplicates, we apply the non-maximum suppression based on mean shift

 2) First step, cluster the circle centers; Second step, cluster the radii. Therefore, each mode of circle center and radius is the circle candidate



$$\mathbf{m}(\mathbf{x}) = \frac{\sum_{i=1}^{N} w(\mathbf{x}_i)\mathbf{x}_i g\left(\left\|\frac{\mathbf{x}-\mathbf{x}_i}{h}\right\|\right)}{\sum_{i=1}^{N} w(\mathbf{x}_i) g\left(\left\|\frac{\mathbf{x}-\mathbf{x}_i}{h}\right\|\right)} - \mathbf{x}$$

Initial circle set → Circle candidate set

Circle candidate generation and validation

- Circle candidate validation

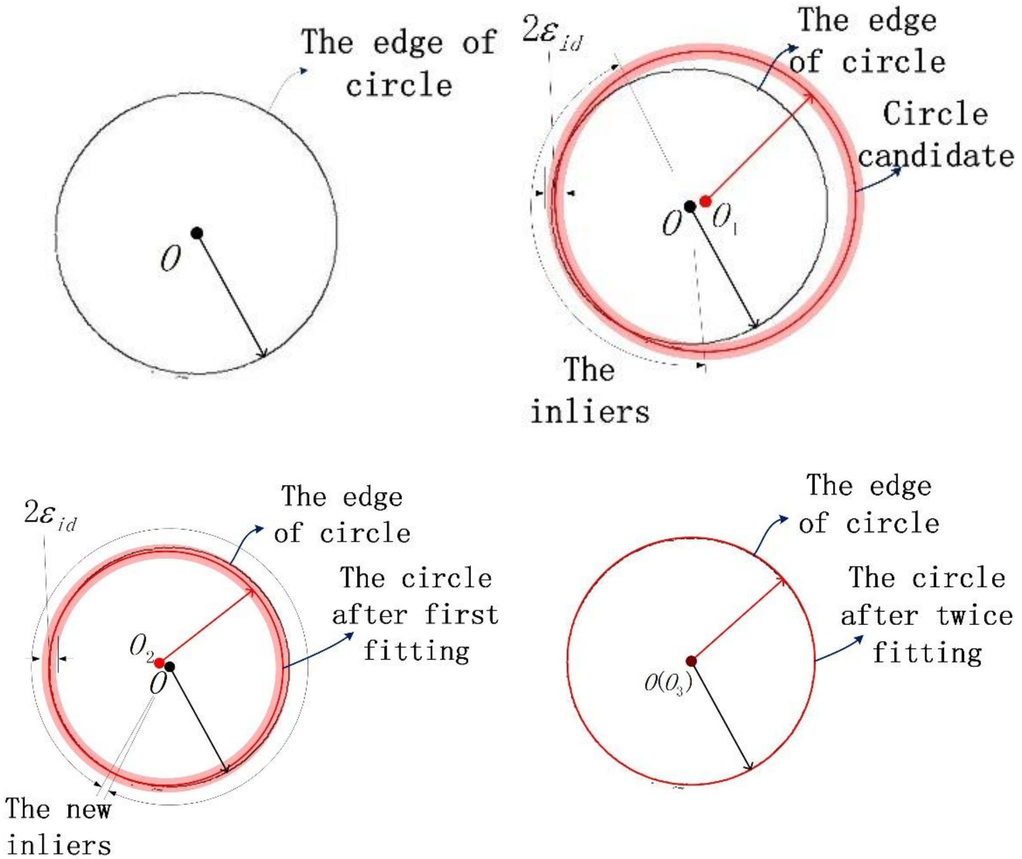
1) We expect that the number of valid inliers of a circle should be larger than $2\pi R T_{ni}$, where T_{ni} is ratio threshold

2) The angle coverage of connected component of valid inliers should be at least T_{ac} degrees

Circle candidate generation and validation

- Twice circle fitting

If the circle after first fitting generates the true circle, its new valid inliers will be more sufficient than the old. Therefore, this observation motivates us for a twice circle fitting to improve the accuracy



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Experimental results

- Datasets
  1) Natural image dataset
  2) PCB image dataset
- Evaluation metrics
  1) Precision = TPs/(TPs + FPs)
  2) Recall = TPs/(TPs + FNs)

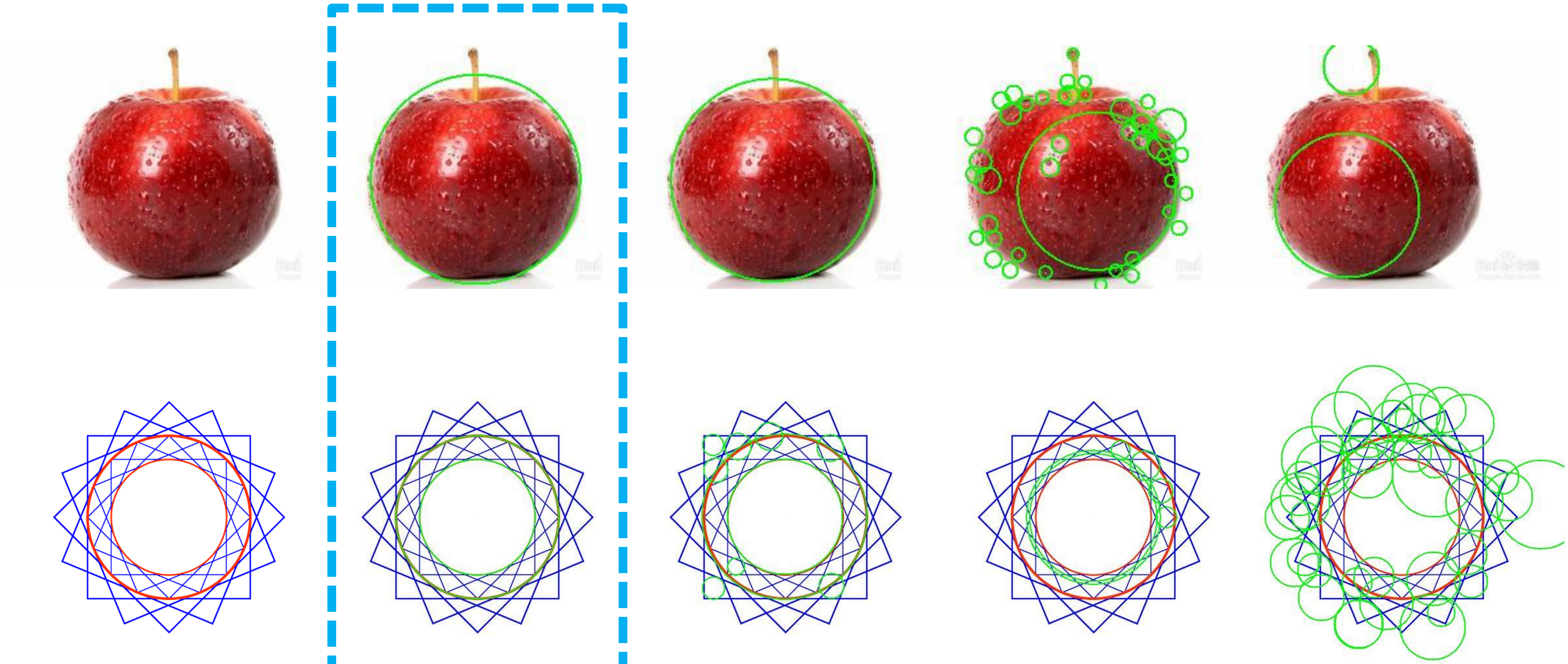
Method type	Precision	Recall	Average time
Our method	**97.26%**	**81.45%**	**284.6 ms**
The method in [1]	86.40%	82.60%	4467.8 ms
CHT	26.36%	61.95%	2457.7 ms
RCD	31.06%	34.99%	190.2 ms

The results in natural image dataset

Method type	Precision	Recall	Average time
Our method	**100.00%**	**94.24%**	**155.3 ms**
The method in [1]	89.06%	97.12%	1160 ms
CHT	35.53%	55.56%	1106.9 ms
RCD	52.27%	18.93%	118.3 ms

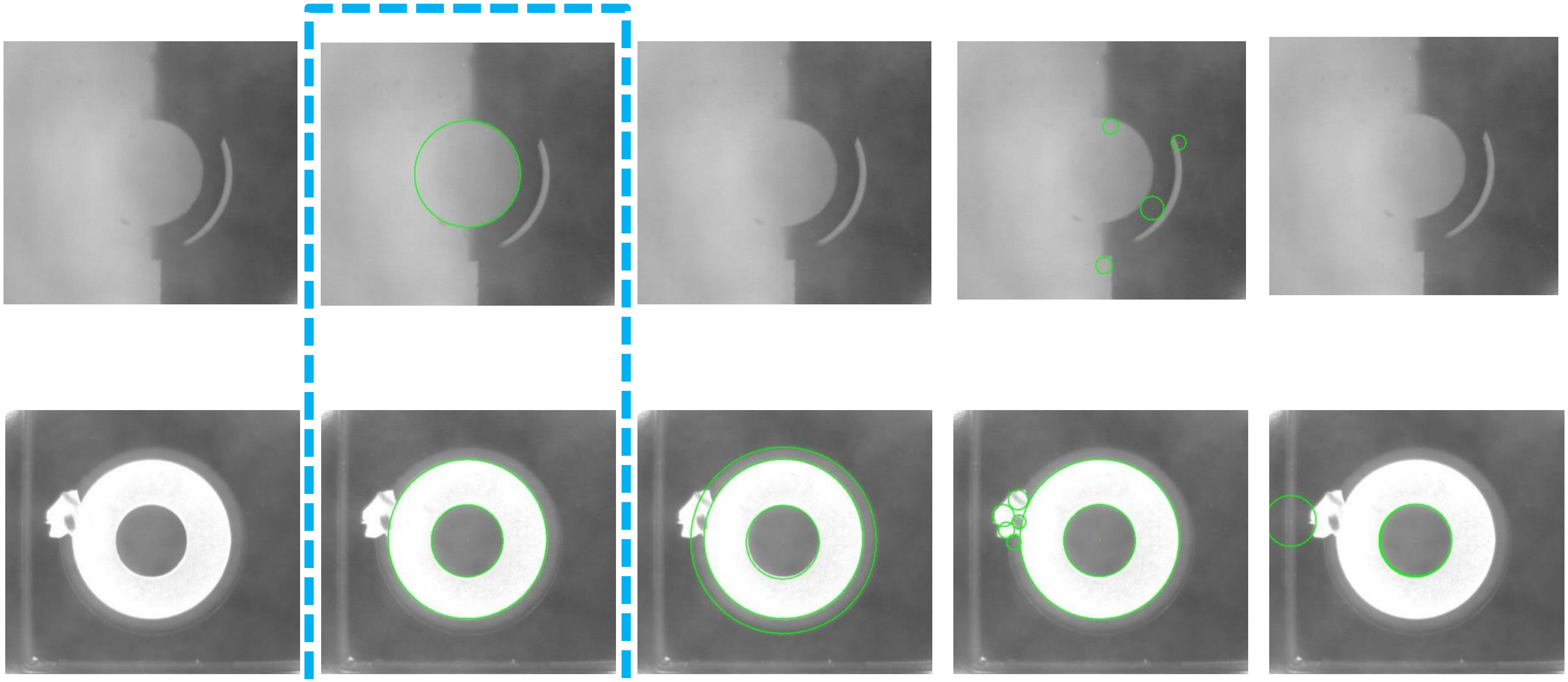
The results in PCB image dataset

Experimental results



Origin image | Our method | The method in [1] | CHT | RCD

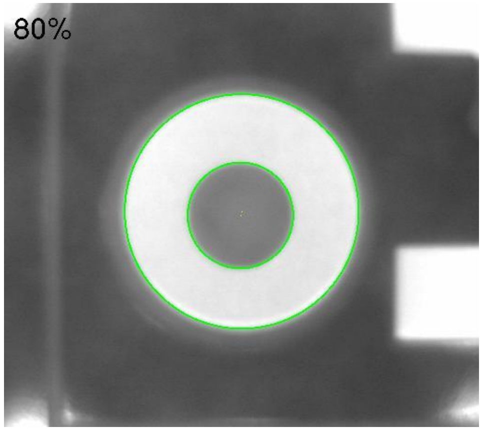
Experimental results

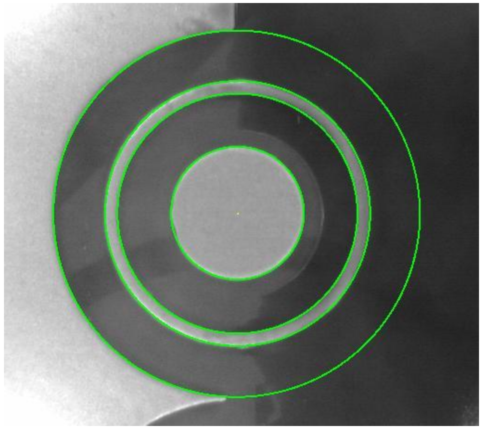


Origin image | Our method | The method in [1] | CHT | RCD

Experimental results

- Examples





<<<Code Link

https://github.com/AlanLuSun/Circle-detection

Contents

Summary

- We propose the concept of arc-support line segment, and point out corresponding property of polarity
- We use the polarity analysis, region restriction and effective criteria to reduce the arc-support line segments pairing time, which improves the circle detection efficiency.
- Validate the circle candidates from the number of inliers and the circle completeness, which increases the algorithm' s robustness
- Improve the circle location accuracy by twice circle fitting

Thanks for listening