Circle Detection by Arc-support Line Segments

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

- 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

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
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
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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
Arc-support line segment extraction

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

3) Denote main direction as $\angle \overrightarrow{AB}$ and the directions of two sub-regions as $\angle \overrightarrow{AC}, \angle \overrightarrow{CB}$
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) origin image.
  (b) 146 LSs are extracted by LSD [2].
  (c) 92 arc-support LSs are extracted by proposed method.

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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**

\[
\begin{align*}
\overrightarrow{AC} \cdot \overrightarrow{ARC_{L1}} & > \rho_d \\
\overrightarrow{AD} \cdot \overrightarrow{ARC_{L1}} & > \rho_d \\
\overrightarrow{CA} \cdot \overrightarrow{ARC_{L2}} & > \rho_d \\
\overrightarrow{CB} \cdot \overrightarrow{ARC_{L2}} & > \rho_d
\end{align*}
\]
Paired line segments analysis

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

  2) The percentage of valid inliers should be larger than $\gamma$. (The inliers that make up $L_1$ and $L_2$ are valid if they satisfy distance tolerance $\epsilon_{id}$ and normal tolerance $\alpha$)

The set of valid pair $\rightarrow$ 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

\[
m(x) = \frac{\sum_{i=1}^{N} w(x_i)x_i g\left(\frac{||x-x_i||}{h}\right)}{\sum_{i=1}^{N} w(x_i)g\left(\frac{||x-x_i||}{h}\right)} - x
\]

Initial circle set $\rightarrow$ 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)

<table>
<thead>
<tr>
<th>Method type</th>
<th>Precision</th>
<th>Recall</th>
<th>Average time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our method</td>
<td>97.26%</td>
<td>81.45%</td>
<td>284.6 ms</td>
</tr>
<tr>
<td>The method in [1]</td>
<td>86.40%</td>
<td>82.60%</td>
<td>4467.8 ms</td>
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<tr>
<td>CHT</td>
<td>26.36%</td>
<td>61.95%</td>
<td>2457.7 ms</td>
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<tr>
<td>RCD</td>
<td>31.06%</td>
<td>34.99%</td>
<td>190.2 ms</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Method type</th>
<th>Precision</th>
<th>Recall</th>
<th>Average time</th>
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</thead>
<tbody>
<tr>
<td>Our method</td>
<td>100.00%</td>
<td>94.24%</td>
<td>155.3 ms</td>
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<tr>
<td>The method in [1]</td>
<td>89.06%</td>
<td>97.12%</td>
<td>1160 ms</td>
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<tr>
<td>CHT</td>
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<td>55.56%</td>
<td>1106.9 ms</td>
</tr>
<tr>
<td>RCD</td>
<td>52.27%</td>
<td>18.93%</td>
<td>118.3 ms</td>
</tr>
</tbody>
</table>

The results in natural image dataset

The results in PCB image dataset
Experimental results

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

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Experimental results

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

- Examples

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

<<<Code Link

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- 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