Detection, Localization and Picking Up of Coil Springs from a Pile

Keitaro Ono, Takuya Ogawa, Yusuke Maeda (Yokohama National University)
Shigeki Nakatani, Go Nagayasu, Ryo Shimizu, Noritaka Ouchi (NHK Spring Co., Ltd.)
Background

- Robotic Bin Picking
  - More flexible than conventional parts feeders
  - Suitable to high-mix production
  - Many previous studies
    - E.g. [Shroff et al. 2011] [Liu et al. 2012]
  - Commercial products available

Not Applicable to Coil Springs
Coil Springs

- Round shape: no vertices, no straight lines
- Succession of identical shapes
- See-through
- Highlights by specular reflection

Those make it difficult to apply conventional bin picking techniques
To Achieve Robotic Bin Picking of Coil Springs

- Approach: Develop a technique dedicated to coil springs
  - Detection: Highlight-based
  - Localization: Stereo vision
  - Picking
Highlight-based Detection of Coil Springs

- Image binarization to extract highlights

End-face Highlights

Side Highlights
Area-based Discrimination of Highlights

Noise  Side Highlights  Noise  End-Face Highlights  Noise

Area [pixel]

Side Highlights

End-face Highlights
Recognition of Coil Springs

- **End-face Highlight**
  - Coil spring in an upright position
  - Ellipse fitting to obtain its representative point

- **Side Highlight**
  - Grouping is necessary
Grouping Side Highlights

- Shape similarity
  - Area
  - Direction of long axis
  - Magnitude of curve

- Relative positioning
  - Constant highlight interval
  - In-line alignment

Calculated with image moments
Example: Recognition

- Coil springs are successfully recognized
- False groups of inside highlights are harmless for picking
Localization of Coil Springs

- Recognize coil springs for left and right images separately
- Find stereo correspondence
Group-Level Correspondence

- End-face highlights
  - Correspondence between centers of fitted ellipses

- Side highlight groups
  - Correspondence between group centroids
  - Group similarity must be checked
    - Number of member highlights
    - Y-coordinates of group centroids
    - Average highlight areas
    - Group orientation
Example: Group-Level Correspondence
Highlight-Level Correspondence

- Group-level correspondence cannot be found in some cases

- Highlight-level correspondence for localization
  - Y-coordinates of highlights
Highlight-Level Correspondence for Horizontally Aligned Highlights

- Cannot find unique highlight-level correspondence
Highlight-Level Correspondence for Horizontally Aligned Highlights

- Use original grayscale images to find correct highlight-level correspondence
  - Block matching

Template Region (Left)  Matched Region (Right)
Example: Highlight-Level Correspondence
Localization of Coil Springs

- **Standard triangulation**
- **Height**
  
  \[ H = L_0 - Z = L_0 - \frac{fT}{(x_l - x_r)P_s} \]

  - pixel size: \( P_s \)
  - Distance to ref. plane: \( L_0 \)
  - focal length: \( f \)
  - baseline length: \( T \)
  - disparity: \( x_l - x_r \)

- **Tilt angle**
  
  \[ \theta = \cos^{-1} \left( \frac{d_{\text{plane}}}{d_{\text{real}}} \frac{ZP_s}{f} \right) \]

  - highlight interval \( d_{\text{plane}} \) [pixel]
  - pitch: \( d_{\text{real}} \) [mm]
Disparity Correction

- Shapes of left and right highlights are not strictly identical
  - Due to positional relationship among a coil spring, the light source and the cameras

- Disparity is corrected using an experimental formula
  \[ d_p \rightarrow d_p + (a\phi + b d_p + c) \]
Picking Strategy

- Picking Order
  - Highest-First
  - Try second highest after picking failure

- Picking Approach
  - Different approaches depending on tilt angle

\[ \theta = 0 \quad 0 < \theta < 90^\circ \quad \theta = 90^\circ \]
Experimental Setup

- **CCD Cameras**
  - Grayscale
  - 1296 × 964
- **LED Spot Illuminator**
- **Manipulator**
  - RV-1A (Mitsubishi Electric)
- **Electric Gripper**
  - ESG1-SS-2815 (TAIYO)
- **Linux PC**
- **Coil Springs**
  - 34 mm
  - 18 mm
Video: Picking Experiment

Bin-picking of Coil Springs with Stereo Vision

Keitaro ONO, Takuya OGAWA, Yusuke MAEDA (Yokohama National University), Shigeki NAKATANI, Go NAGAYASU, Ryo SHIMIZU and Noritaka OUCHI (NHK SPRING CO., LTD.)
Picking Results in Five Experiments

- 77% success for each picking trial
- 94% success for each spring (with multiple retries)

<table>
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<tr>
<th>Experiment</th>
<th>Number of Picking Trials</th>
<th>Number of Picked Coil Springs</th>
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<tr>
<td>1</td>
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</tbody>
</table>

Graph showing the number of picking trials and the number of picked coil springs for five experiments.
Picking Failures

- Collisions between chuck and part box
- Collisions between chuck and other coil springs
- Collision-free approaching should be implemented
Summary

Conclusion
- A bin picking method dedicated to coil springs was presented
- Coil springs can be detected with highlights on them and localized with stereo vision
- Successful bin picking was demonstrated

Future Work
- Collision avoidance to reduce picking failures