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# Deep Learning-Based Connector Detection for Robotized Assembly of Automotive Wire Harnesses


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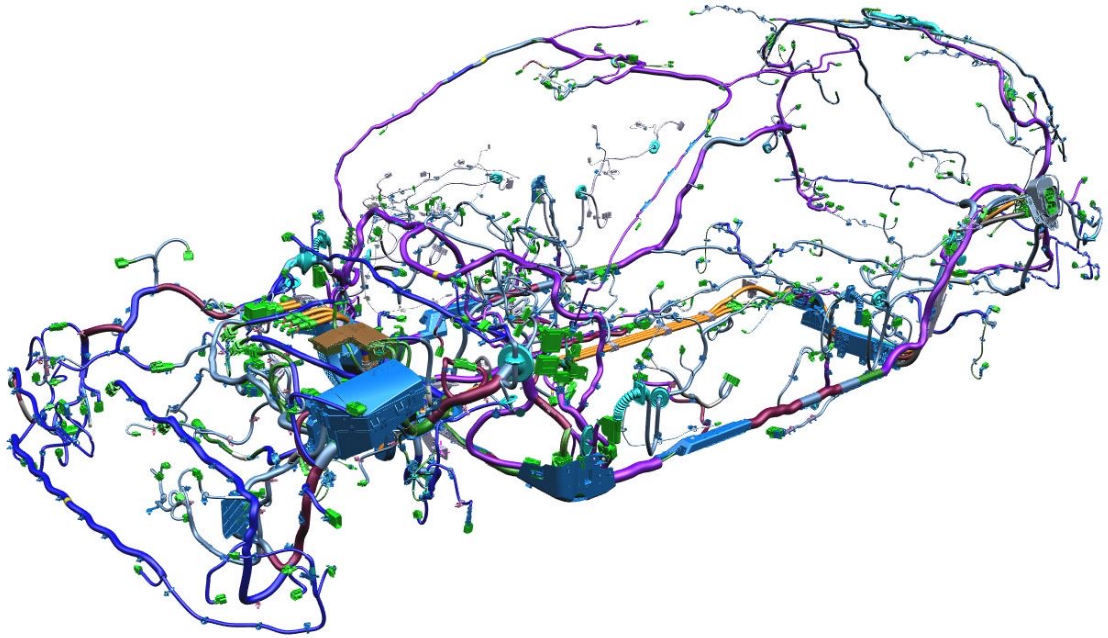
# Wire harnesses



| Year 2000 | Year 2003 | Year 2008 | Year 2020 |
|---|---|---|---|
| 1000 m | 1500 m | 2000 m | 2800 m |

(Images provided by Volvo Car Corporation)

Essential infrastructure

Critical to guarantee the assembly quality

Increasing usage

# Wire harness assembly

Current assembly operations

Manual

Skill-demanding

Problems

Quality

Productivity

Ergonomics

# The mating of connectors

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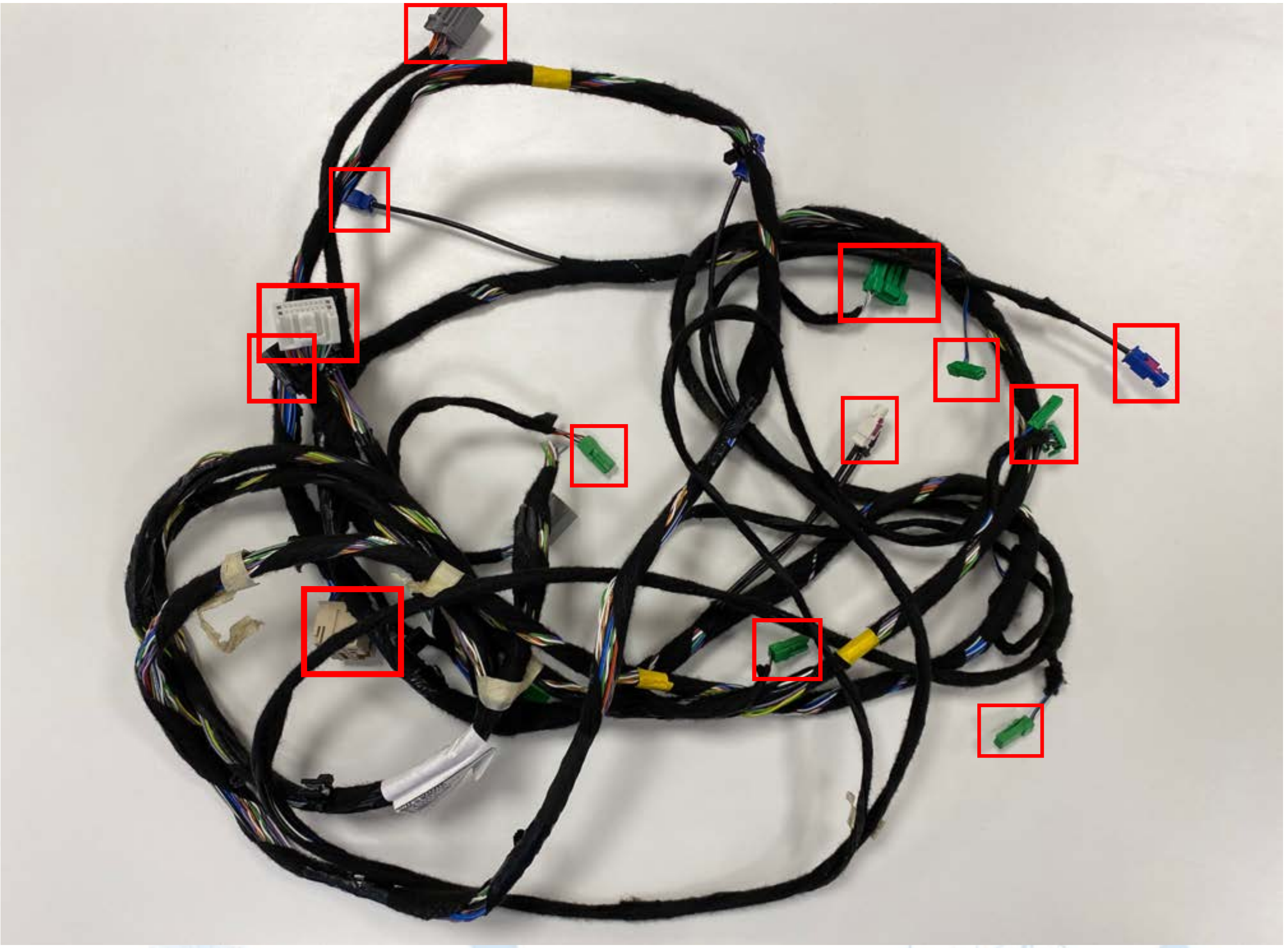

Critical for the connection and functioning of wire harnesses

Repetitive operation
(Locate, grasp, assemble)

Ergonomic issues
(High-pressure pressing)

**Connector detection for robotic grasping and assembly**

# Previous research on connector detection

- High-speed vision system
- Corner detection

Tamada et al. [1] (2013)

- Multiple connector
- Single-class detection

Yumbla et al. [2] (2020)

Rule-based methods

Learning-based methods

Zhou et al. [3] (2020)

- One pair of connectors

## Deep learning-based multi-class connector detection

- Are deep learning-based object detectors effective on connector detection?
- What are the potential obstacles for achieving a practical learning-based connector detection?

[1] T. Tamada, Y. Yamakawa, T. Senoo, and M. Ishikawa, "High-speed manipulation of cable connector using a high-speed robot hand," in 2013 IEEE International Conference on Robotics and Biomimetics (ROBIO), 2013, pp. 1598–1604.
[2] F. Yumbla, M. Abeyabas, T. Luong, J.-S. Yi, and H. Moon, "Preliminary connector recognition system based on image processing for wire harness assembly tasks," in 2020 20th International Conference on Control, Automation and Systems (ICCAS), 2020, pp. 1146–1150.
[3] H. Zhou, S. Li, Q. Lu, and J. Qian, "A practical solution to deformable linear object manipulation: A case study on cable harness connection," in 2020 5th International Conference on Advanced Robotics and Mechatronics (ICARM), 2020, pp. 329–333.

# A dataset of connectors

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MX34


A0


A1


B0


B1


C


D


E

MX80


L


M


N


O


P

MCON 1.2 LL


F


G


H


I


J


K

MX81


Q


R

# Image collection

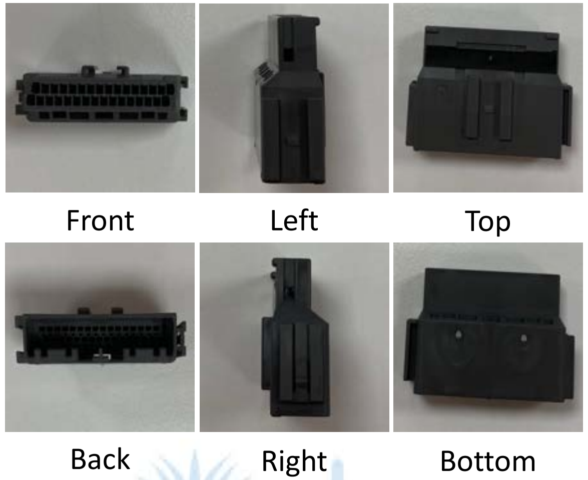
Connector dataset (360)

Mixed connectors (60)

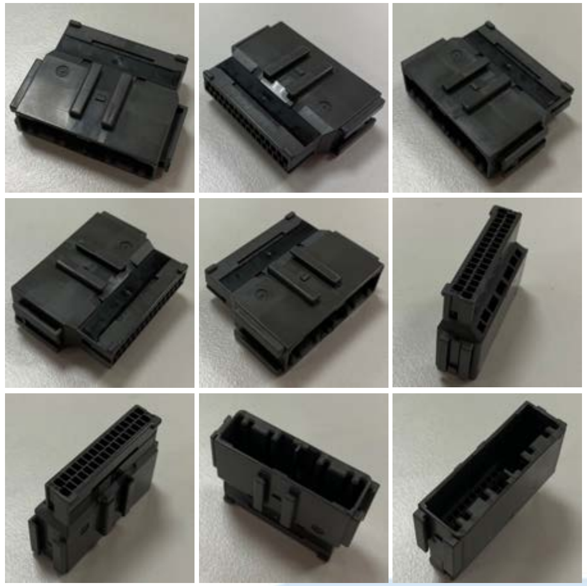
Images of mixed connectors
(60 images)

Single connector (300)

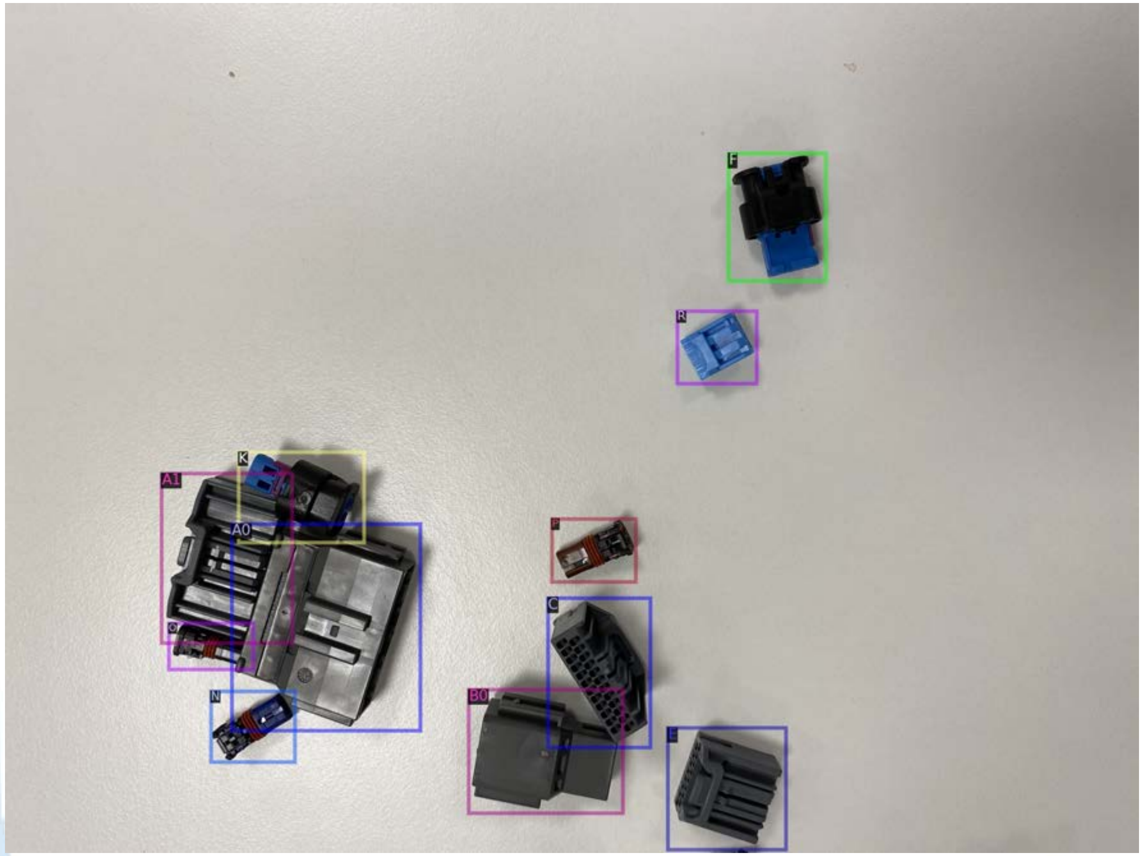
Profile images
(6 images/connector)

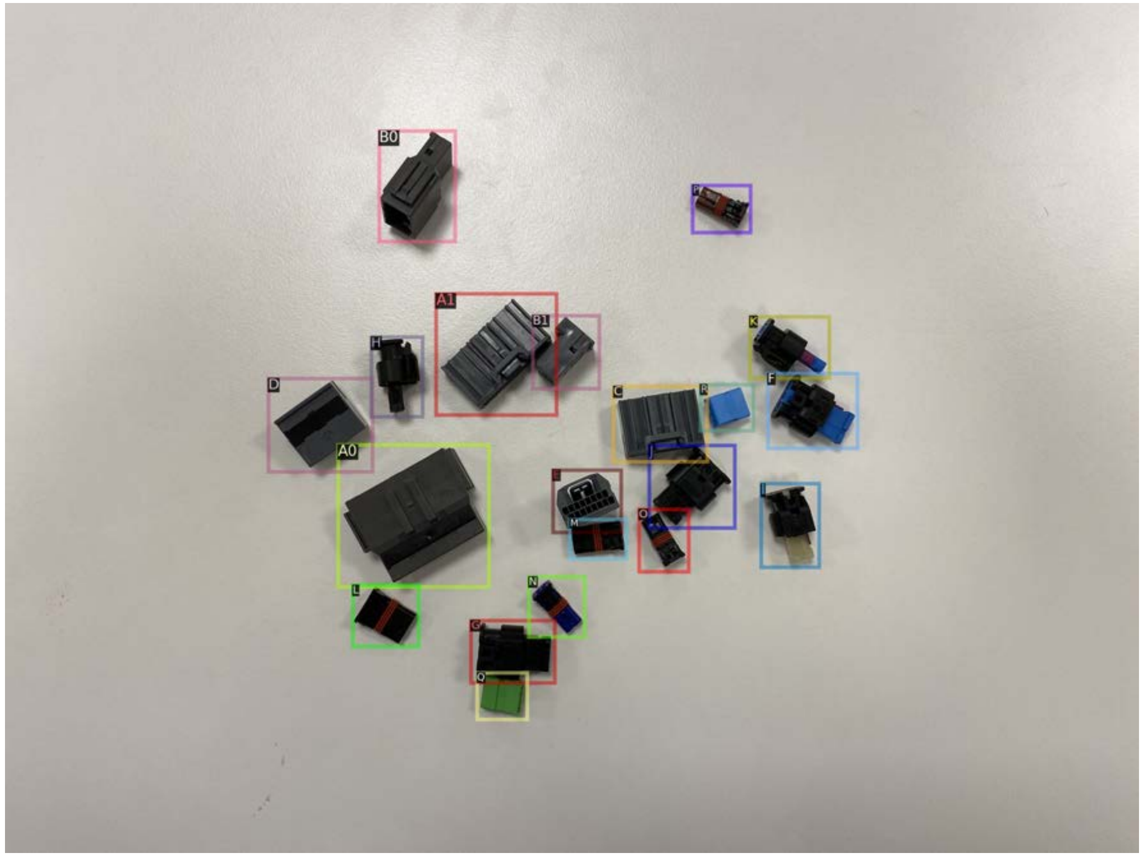



Random-view images
(9 images/connector)



# Image annotation





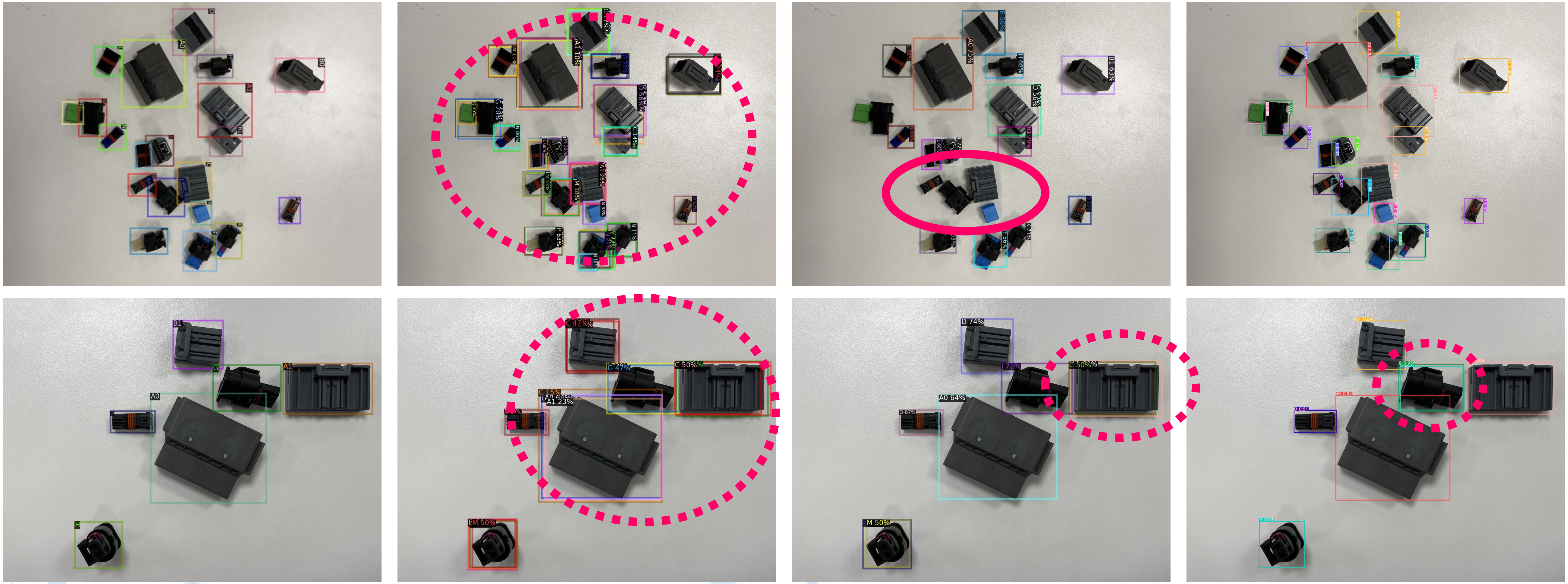
- Annotation method followed PASCAL visual object classes (VOC) challenge 2007[1]
- Image annotation platform: Labelme[2]

[1] M. Everingham, L. Van Gool, C. K. Williams, J. Winn, and A. Zisserman, "The pascal visual object classes (voc) challenge," International journal of computer vision, vol. 88, pp. 303–308, 2009.
[2] "Labelme," https://github.com/wkentaro/labelme, accessed: 2023-02-16.

# Evaluation

Missed
Overlapped





Ground truth | Faster R-CNN[1] (0.1) | Faster R-CNN[1] (0.5) | YOLOv5[2]

[1] S. Ren, K. He, R. Girshick, and J. Sun, "Faster r-cnn: Towards realtime object detection with region proposal networks," in Advances in Neural Information Processing Systems, C. Cortes, N. Lawrence, D. Lee, M. Sugiyama, and R. Garnett, Eds., vol. 28. Curran Associates, Inc., 2015.
[2] "Yolov5," https://github.com/ultralytics/yolov5, accessed: 2023-02-07.

# Evaluation

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The Precision (%) of Faster R-CNN[1] with Threshold Values of 0.1 and 0.5 and YOLOv5[2] Among Classes.

| | Precision (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Class | A0 | A1 | B0 | B1 | C | D | E | F | G | H |
| Faster R-CNN[1] (0.1) | **83.2** | 70.3 | 0.0 | 57.3 | 32.8 | **13.2** | 6.7 | 70.1 | **52.4** | 40.4 |
| Faster R-CNN[1] (0.5) | **83.2** | 48.0 | 0.0 | 48.4 | 0.0 | 0.0 | 0.0 | 70.1 | 30.3 | 40.4 |
| YOLOv5[2] | 76.4 | **79.2** | **100.0** | **73.8** | **69.7** | 0.0 | **47.2** | **100.0** | 30.9 | **90.7** |
| Class | I | J | K | L | M | N | O | P | Q | R |
| Faster R-CNN[1] (0.1) | 45.0 | 48.6 | **80.2** | 80.0 | 60.0 | **93.3** | 63.2 | 72.4 | 35.0 | 78.8 |
| Faster R-CNN[1] (0.5) | 0.0 | 0.0 | **80.2** | 80.0 | 30.3 | **93.3** | 50.4 | 72.4 | 0.0 | 67.2 |
| YOLOv5[2] | **88.5** | **53.0** | 63.2 | **85.5** | **100.0** | 91.6 | **96.4** | **94.6** | **93.0** | **96.8** |

The Mean Average Precision (%) of Faster R-CNN[1] with Threshold Values of 0.1 and 0.5 and YOLOv5[2].

| | $mAP_{50}$ | $mAP_{50-95}$ |
|---|---|---|
| Faster R-CNN[1] (0.1) | 65.7 | 54.1 |
| Faster R-CNN[1] (0.5) | 47.1 | 39.7 |
| YOLOv5[2] | **88.5** | **82.1** |

Deep learning-based detection models are effectiveness.

Missed, overlapped, unstable detection results exist.

**A benchmark dataset is needed!**

Training

Evaluation

[1] S. Ren, K. He, R. Girshick, and J. Sun, "Faster r-cnn: Towards realtime object detection with region proposal networks," in Advances in Neural Information Processing Systems, C. Cortes, N. Lawrence, D. Lee, M. Sugiyama, and R. Garnett, Eds., vol. 28. Curran Associates, Inc., 2015.
[2] "Yolov5," https://github.com/ultralytics/yolov5, accessed: 2023-02-07.

# Potential hindrance

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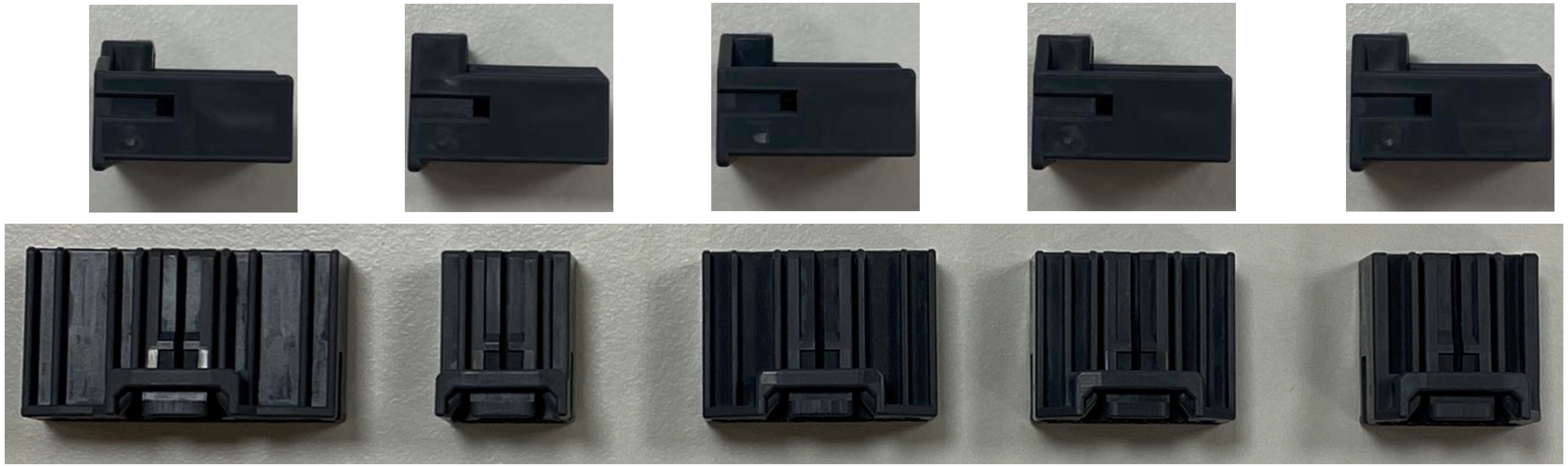
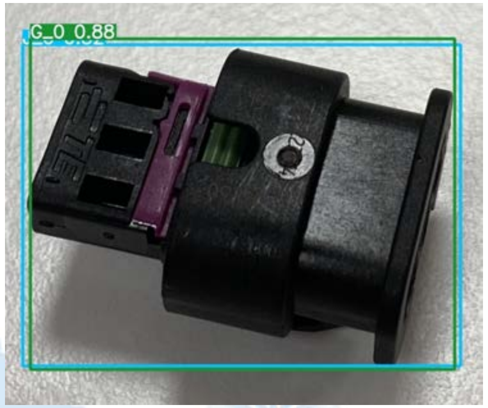
Left
Top



A1 B1 C D E

(Almost) Identical features




G
J

Front Back Left Right Top Bottom

Infeasible features

# Conclusion and future work

- This study verified the effectiveness of deep learning-based connector detection.
- A dataset of automotive wire harness connectors was collected for evaluation.
- This study identified the insufficient dataset and the current design of connectors as hindrances of detection.
- A benchmark dataset is desired for better training and evaluation.
- Further research will exploit the structure of wire harnesses and multi-view image-/video-based detection.

[1] S. Ren, K. He, R. Girshick, and J. Sun, "Faster r-cnn: Towards realtime object detection with region proposal networks," in Advances in Neural Information Processing Systems, C. Cortes, N. Lawrence, D. Lee, M. Sugiyama, and R. Garnett, Eds., vol. 28. Curran Associates, Inc., 2015.
[2] "Yolov5," https://github.com/ultralytics/yolov5, accessed: 2023-02-07.

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Acknowledgement: