Deep-Learning-Based Rebar Pose Estimation for Robotic Manipulation

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Background

- As the labor force in the construction industry decreases and costs rise, automating construction tasks with robots has become a major research focus. This trend aims to enhance efficiency and address the shortage of skilled labor.
- Rebar work is crucial in constructing reinforced concrete structures, yet it predominantly relies on manual labor. This approach is both time-consuming and labor-intensive, often leading to human error.
- 6D rebar pose estimation is essential for achieving automated rebar engineering, though it is still underexplored. Accurate pose estimation allows robotic arms to perform rebar assembly, tying, and quality inspection efficiently and precisely.
- Our research seeks to develop a reliable and cost-effective perception method for automated rebar engineering. By reducing reliance on manual labor and minimizing human error, this method aims to improve productivity and quality in construction.

Objectives

- Construct the **first** point cloud dataset of complex rebar structures, including high-quality annotated point clouds of rebar cages and rebar meshes.
  - Develop an open-source synthetic data generation pipeline to rapidly generate large amounts of data for training DL-based models.
- Develop a deep learning-based 3D point cloud segmentation method for accurate rebar pose estimation and dimensional quality inspection.
  - Automate the pipeline of the detection (i.e., **semantic segmentation**) and pose estimation (i.e., **instance segmentation**) of rebar in construction environments.
  - Reconstruct the rebar-background point cloud using **Structure-from-Motion** algorithms.
  - Provide real-time positional information for robotic arms to perform pick-and place tasks.

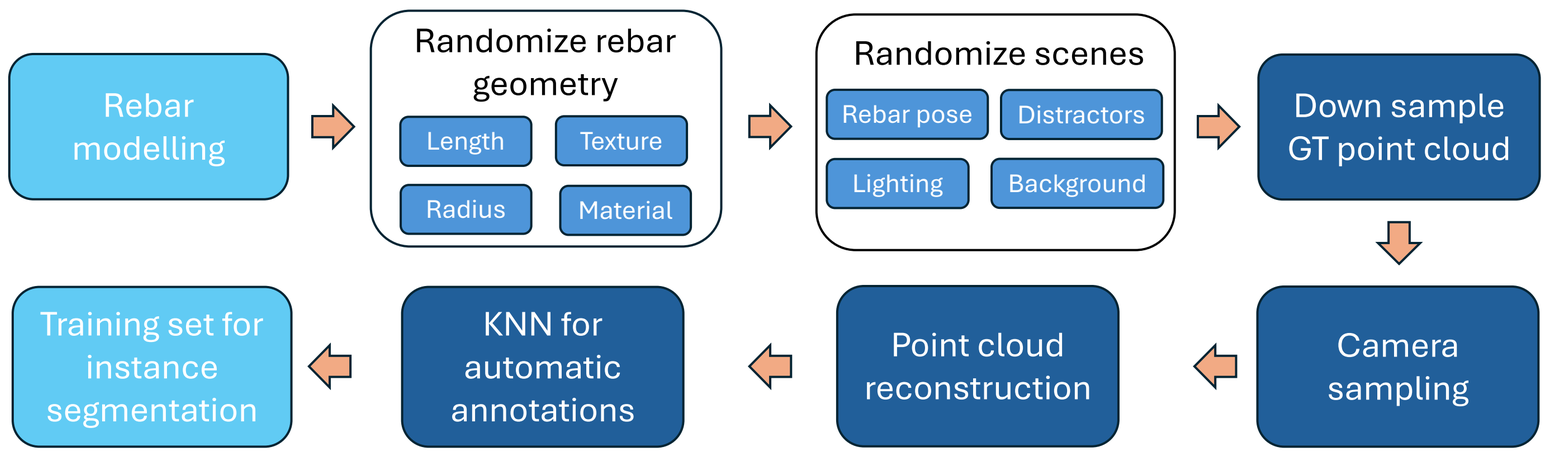
Future Works

- Test on complex rebar structures with random occlusions and background clutter.
- Incorporate more types of rebar into the segmentation model, beyond stirrup and straight rebar.
- Enhance the data generation pipeline to simulate TLS scanner data, expanding dataset compatibility and application scenarios.

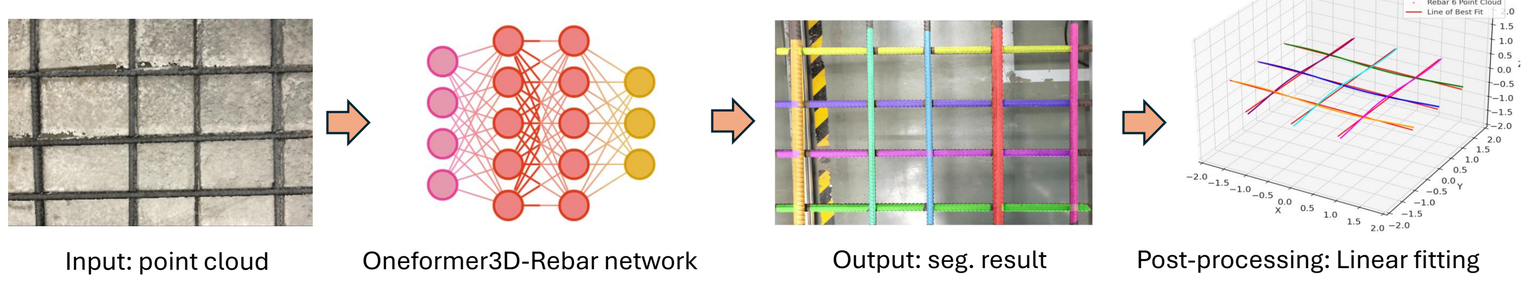
Methods

Data Generation Pipeline

- To train deep learning-based point cloud segmentation models, a large amount of high-quality 3D point cloud dataset is required. However, annotating these point clouds is extremely time-consuming and labor-intensive. Therefore, we have introduced a new automated pipeline for generating synthetic 3D datasets, which eliminates the need for manual data annotation.



Deep Learning-based Pose Estimation

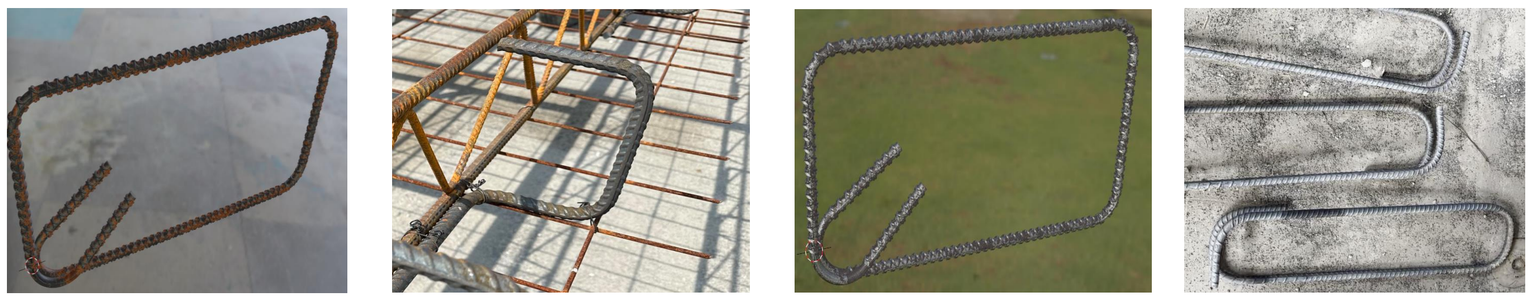


Input: point cloud | Oneformer3D-Rebar network | Output: seg. result | Post-processing: Linear fitting

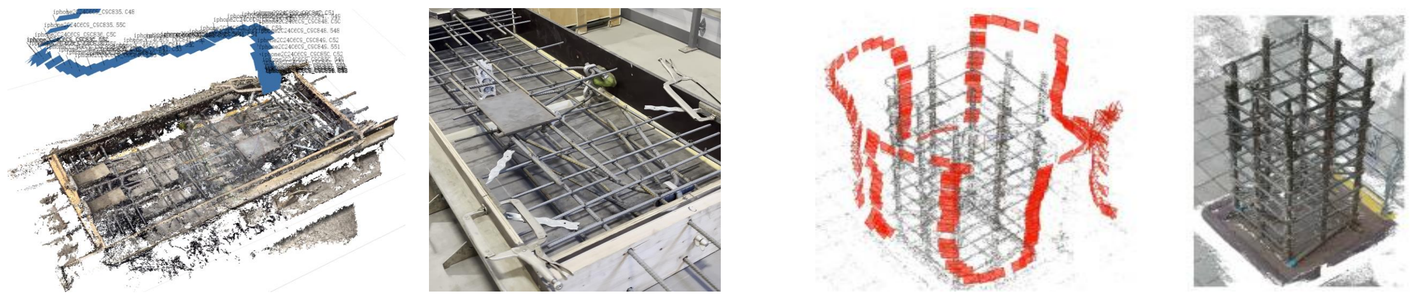
- The key to rebar pose estimation lies in accurately identifying the rebar within the 3D point cloud. This involves performing semantic and instance segmentation on the rebar and its surrounding background using a Transformer-based network. After instance segmentation, we can fit the rebar's point cloud to a straight line, allowing us to determine the rebar's pose and its relative position to other rebars.

Results

Open-source Rebar Point Cloud Dataset

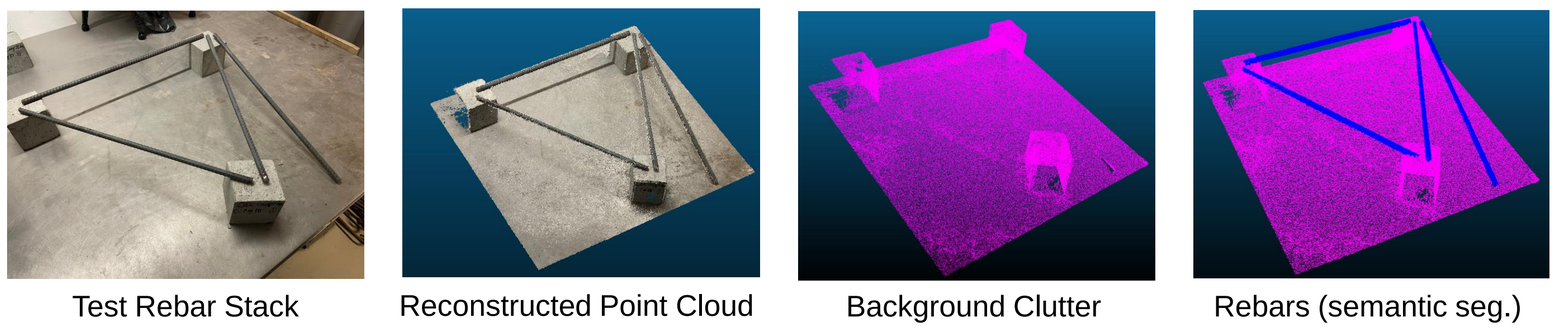


Point Cloud Reconstruction [1]



Slab Reconstruction | Column Reconstruction

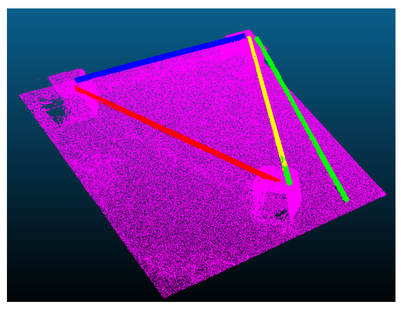
Instance Segmentation Results



Test Rebar Stack | Reconstructed Point Cloud | Background Clutter | Rebars (semantic seg.)

Classes	straight	stirrup	clutter	miou	acc	acc_cls
Results	0.9699	nan	0.9859	0.9779	0.9903	0.9856

Classes	AP_0.25	AP_0.50	AP	Prec_0.50	Rec_0.50
straight	1.0000	1.0000	0.9338	1.0000	1.0000
stirrup	nan	nan	nan	nan	nan
clutter	1.0000	1.0000	1.0000	1.0000	1.0000
Overall	1.0000	1.0000	0.9669	1.0000	1.0000



Rebars (instance seg.)

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