P-87: From 3D Scans to Buildable Structures: Visual-Guided Assembly via Residual RL

P-87: ３Ｄスキャンから構築可能な構造物へ：残渣強化学習による視覚誘導アセンブリ

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Abstract

- Societies facing labor shortages in a growing *custom based industry*, require automated and adaptive production to maintain supply chains.
- The shift to **Industry 5.0** requires robot to be compliant with flexible-driven actions capable of safe collaboration with humans.

Limitations of Existing Methods:
In the context of Sequential Part Assembly, current approaches fail to physically realize structure from 3D models because they rely on idealized and privileged information from a simulation, whereas others lack physical feedback.

Research background

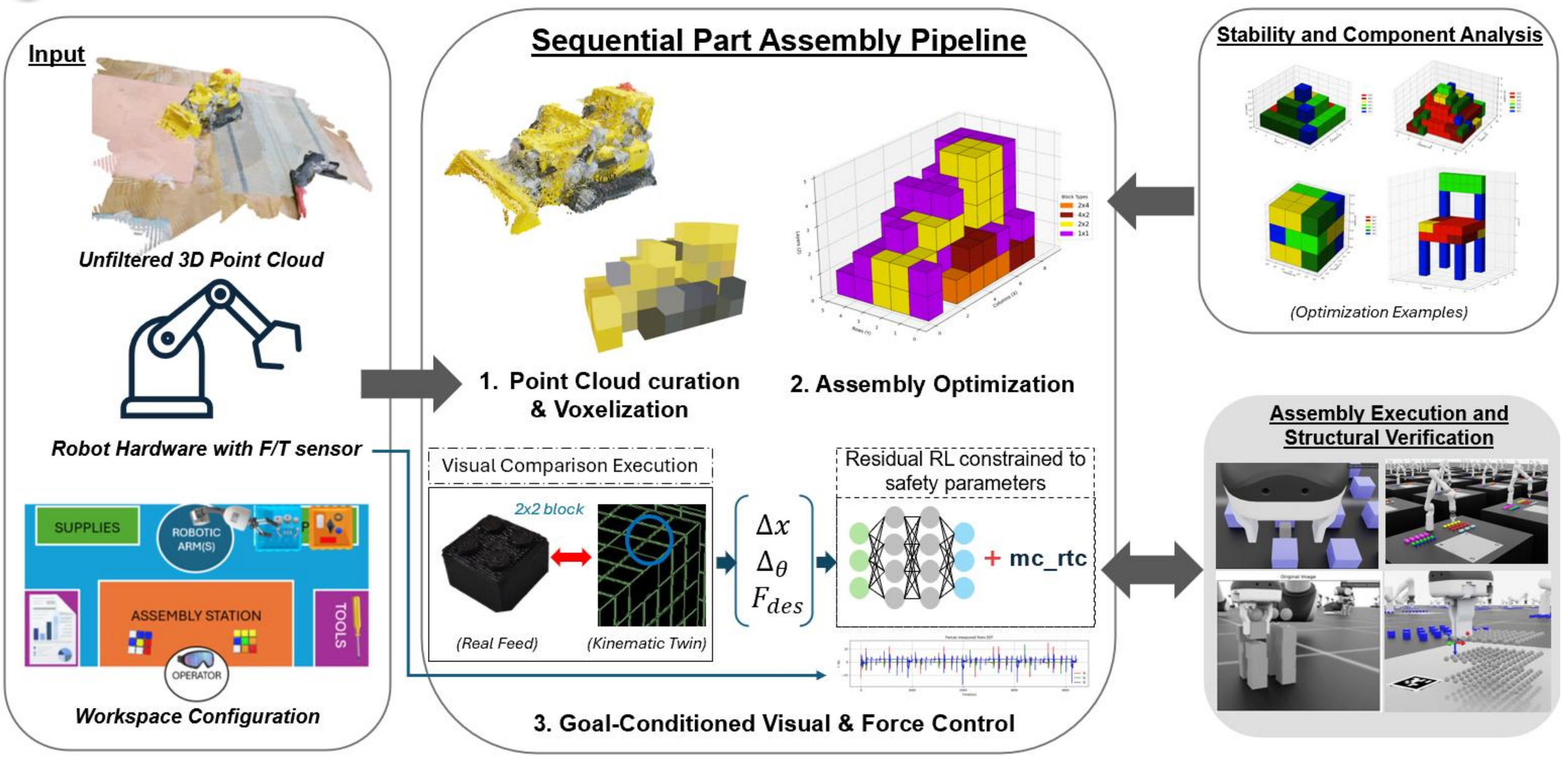
- Adaptability
- Compliance
- Safeness

→ **INDUSTRY 5.0**

The relevance of the research builds on advances in sequential manipulation policies (e.g., **Sequential Dexterity**, Chen et al.,2023), RL-based assembly strategies like **Fabrica** (Tian et al.,2025), and assembly sequencing prediction using **SPAFormer** (Xu et al.,2024).Additionally, lightweight Vision-Language Action models enable its execution in consumer grade computers.

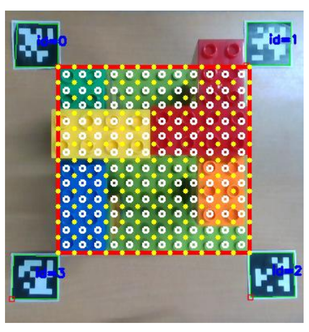
This research aims to demonstrate the efficacy of Contact-Rich Assembly using Residual RL using Sim-to-Real Visual Discrepancy.

Proposed method

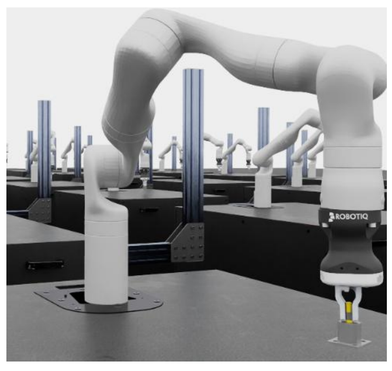


1. Point clouds are *captured* and *curated* through manual cropping, noise filter and orientation alignments for Voxelization. Down sampling is done to create evenly spaced grids (geometrical simplification).
2. A *greedy layer-by-layer* strategy minimizes the number of assembly steps and produces stable, interlocked assembly sequences
3. To address the deployment gap, a Hybrid Digital Twin Architecture is proposed to unify perception and safety:
   - **Visual Verification:** Use of a Lightweight Visualizer (OpenGL) to compare the *current assembly* and *expected target states*, by feeding structural edges (Canny) and depth differences.
   - **Residual Impedance Policy**: High Level RL agent outputs position and orientation displacement (Δ_x, Δ_θ)commands to a low-level Impedance Controller (*mc_rtc*), to enforce force constraints (F_{des}).

Work in Progress



ArUco markers are used to define the grid space for assembly. Camera calibration is still required to test integration with OpenGL + ROS2.



The current RL agent is based on a Peg-in-Hole tasks, which does not consider Force/Torque data yet.

Issue: Base implementation (Panda Robot) trains 10x faster than with our Kinova Model (.usd file).

Conclusion / Future Work

This work proposes a Robotic manipulation pipeline accounting for Force/Torque sensing, 3D perception, and VLA's for adaptive and safe to interact assembly tasks. By combining hybrid compliance control with structured geometric reasoning, this approach aims to bridge robotics precision with human-like adaptability.

Future work considers automated point cloud curation, integrating insertion policies into the SVLR workflow (Samson et al.,2025), and validating the system on physical robotic platforms in real industrial context scenarios.