Application of 3D Vision in Collaborative Robotics for Automated Machine Feeding

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Introduction

Project Overview

Background:

- Cork trace orientation and automation are critical for improving cork production quality.
- Collaborative robotics integrated with 3D vision systems can revolutionize industrial automation.

Project Objectives:

- Develop a 3D vision system for mapping and identifying bulk cork pieces.
- Integrate the vision system with a collaborative robot for feeding production machines.
- Validate system performance in precision, efficiency, and safety.

Problem Analysis

Problem Analysis

Challenges in Cork Industry:

- Handling variability in size, shape, and orientation of cork pieces.
- Addressing natural variations in color, texture, and appearance due to cork being a natural product.

User and Context:

- Users: Manufacturers of cork stoppers.
- Context: Factory automation for cork production and finishing processes.

Key Questions:

- How can 3D vision systems enhance collaborative robot functionality?
- What methods ensure high precision in cork trace orientation detection?

Vision System Design

Computer Vision Techniques

Techniques and Tools:

- Point Cloud Processing: Filtering, segmentation, and clustering using `open3d`.
- Noise Removal: Statistical outlier removal for cleaner data.
- Clustering: Conditional Euclidean Clustering (CEC) to segment cork traces.
- RGB Mapping: Overlaying clusters onto RGB images for enhanced visualization.

Justification:

- Combines efficiency of traditional analytical methods with robustness of modern clustering.
- Suitable for handling variability in cork pieces.

Implementation

System Workflow

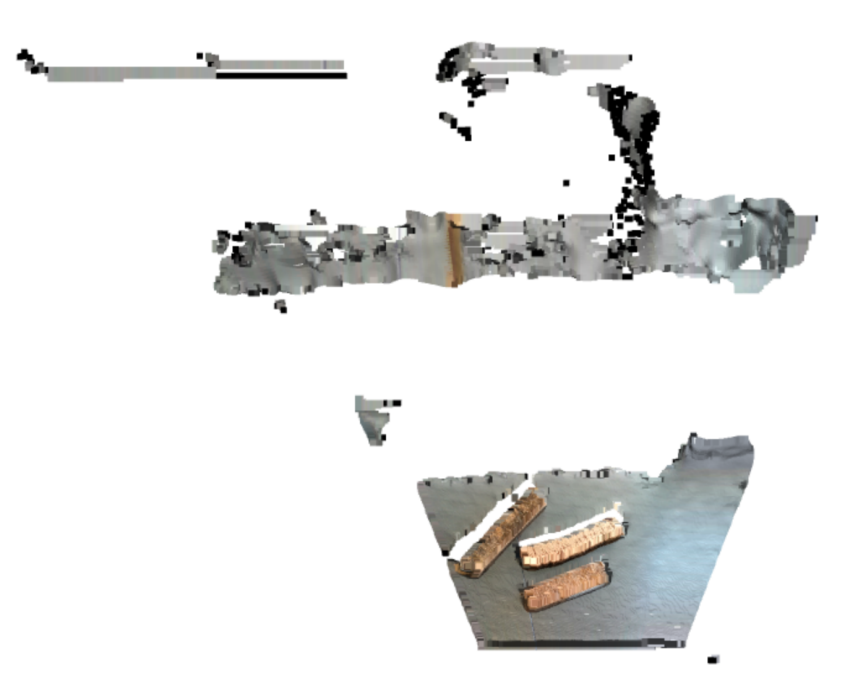
Workflow Stages:

1. **Data Acquisition**: 3D point cloud capture using Intel RealSense D435i.
2. **Pass-Through Filtering**: Reduce point cloud size by isolating regions of interest.
3. **Floor Removal**: Segment and exclude planar surfaces to isolate cork pieces.
4. **Downsampling**: Apply voxel grid filtering to reduce point cloud density.
5. **Outlier Removal**: Eliminate noise using statistical outlier removal.
6. **Clustering**: Use Conditional Euclidean Clustering (CEC) to detect cork piece groups.
7. **Mapping**: Overlay clustered points onto RGB images for validation.

Original Image

Description:

- Shows the unprocessed point cloud of the cork pieces.
- Captured using Intel RealSense D435i.



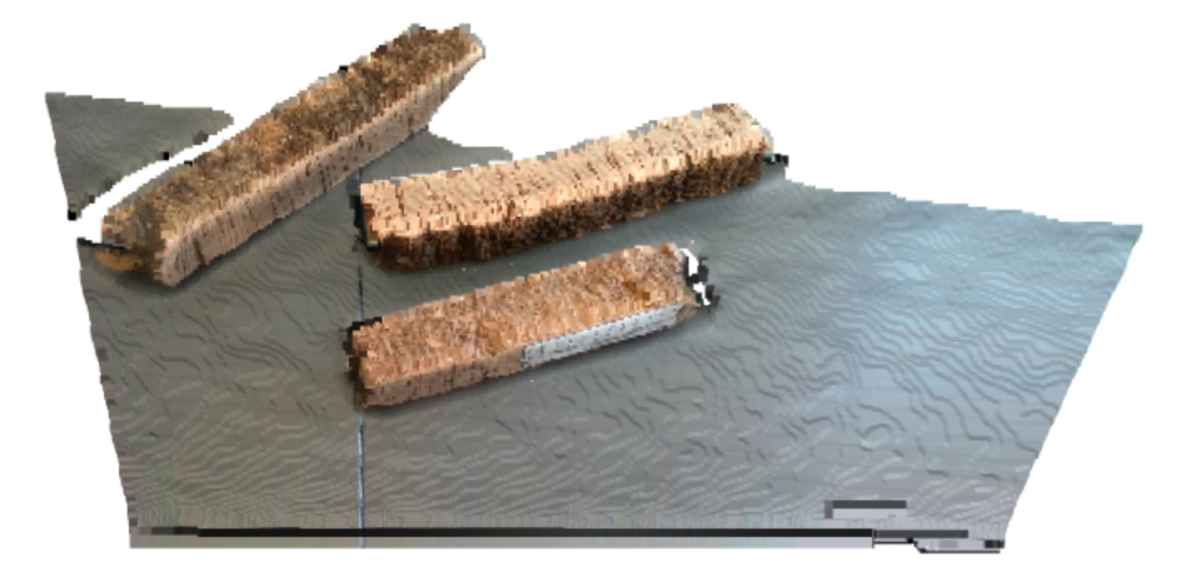
Results:

- Raw data ready for processing (no filtering or clustering applied yet).

Pass-Through Filtering

Description:

- Reduces the dataset size by focusing on regions of interest.
- Filters applied along X, Y, and Z axes to isolate relevant points.



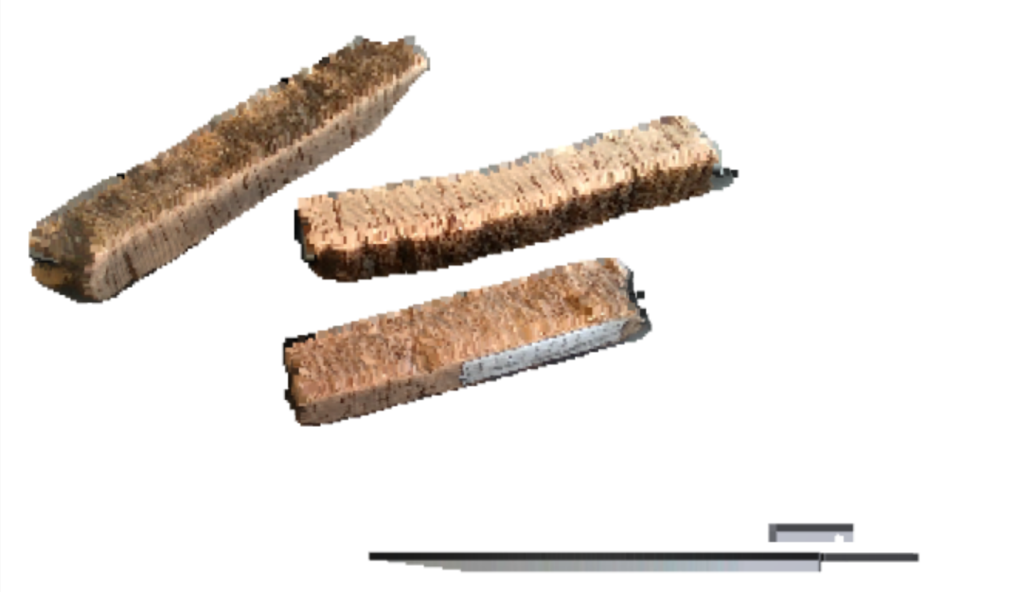
Results:

- Significant reduction in point cloud size.
- Retained only the cork-relevant sections of the cloud.

Floor Removal

Description:

- Identifies planar surfaces and removes them to isolate cork pieces.
- Utilizes RANSAC-based plane segmentation.



Results:

- Successfully excluded floor points.
- Enhanced focus on cork clusters in 3D space.

Downsampling and Noise Removal

Description:

- Downsampling: Voxel grid reduces point cloud density for computational efficiency.
- Noise Removal: Statistical outlier removal eliminates scattered points.

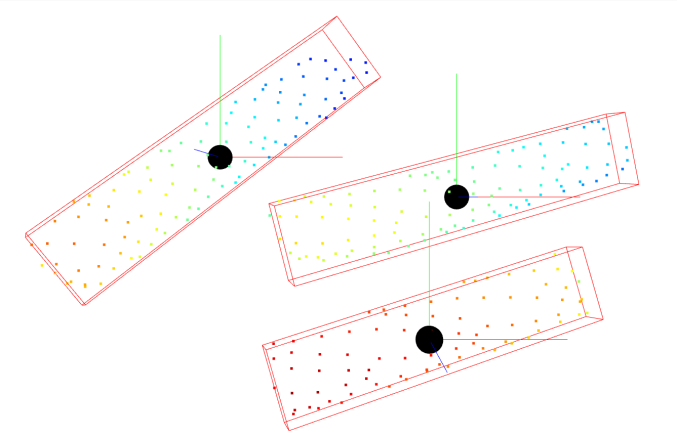
Results:

- Downsampled point cloud retains key structural features.
- Improved clarity and accuracy for clustering stages.

Clustering and Oriented Bounding Boxes

Description:

- **Clustering:** Applied Conditional Euclidean Clustering (CEC) to segment cork pieces.
- **OBBs:** Generated Oriented Bounding Boxes to define spatial extent and orientation of clusters.



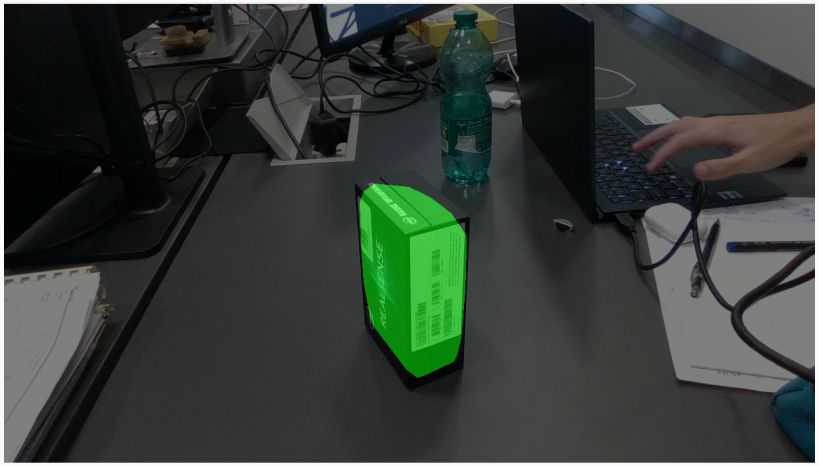
Results:

- Segmented cork pieces into clusters using CEC.
- OBBs accurately defined cluster orientations.
- Ready for further analysis, such as face detection.

Mapping and Masking onto RGB Image

Description:

- Projected 3D clusters onto the 2D image plane.
- Created a smooth green mask overlaid onto the RGB image.



Results:

- Enhanced visualization of cork cluster regions.
- Provided a foundation for future Machine Learning integration.

Results and Analysis

Preliminary Results Overview

Successes:

- Segmentation and clustering of cork pieces using 3D vision techniques.
- Effective overlay of processed clusters onto the RGB image.

Future Challenges:

- Improve the quality of the images (Hole filling, Post Processing Filters, Laser projector settings).
- Identify and segment individual faces of the cork strips (e.g., top, sides).
- Extract the largest rectangle from the identified faces to enable feature extraction.
- Develop robust feature extraction for machine learning models to detect the back of cork strips.

Conclusion and Future Work

Conclusion

- Developed a pipeline up to the RGB masking stage for cork piece segmentation and visualization.
- Demonstrated effective clustering and initial masking techniques.
- Set the foundation for extracting features required for machine learning-based orientation detection.

Future Work

Immediate Goals:

- Enhance image acquisition techniques to ensure cork pieces are captured with more detail.
- Implement segmentation techniques to identify individual faces (top, side, etc.) of the cork pieces.
- Extract geometric features from identified faces to prepare for machine learning models.

Long-Term Goals:

- Optimize the pipeline for real-time processing.
- Develop and train machine learning models for cork orientation detection using extracted features.