Multi-Robot 3D Scanner System for Reconstruction

Introduction

- **3D scanning** enables users worldwide to capture, and share detailed digital models for inspection, manufacturing and virtual interaction. These models reveals hidden features and enables global collaboration
- **Robotic automation** and **3D vision** enhances task performance by providing precise spatial awareness for accurate navigation and manipulation.
- **Amazon** challenged our team to develop a cohesive 3D scanning system using robotic arms. The result is a controlled and repeatable process that automates both object handling and scanning, which ensures accurate and efficient results across a wide range of objects.

Objectives

- Develop a practical system for high-quality, full-color 3D scanning of objects.
- Use a single coordinated robot to manipulate both the object and the scanner.
- Employ a RealSense scanner to capture detailed, watertight 3D models.
- Utilize control algorithms to adapt to different shape, minimize occlusion, and ensure accuracy.

Hardware Approach

- **XArm6 (Robotic Arm):**
  - Equipped with an **Intel RealSense D415** camera mounted above the gripper for top-down depth and color scanning.
  - Controlled via a **Python** wrapper within a ROS2 node to enable precise, real-time motion planning.
- **Turntable:**
  - A custom motorized turntable using a **stepper motor** and timing belt in a pulley system to enable **360° scanning** by rotating objects of various sizes and weights.

Figure 1: Hardware Setup

Figure 2: Reference Points

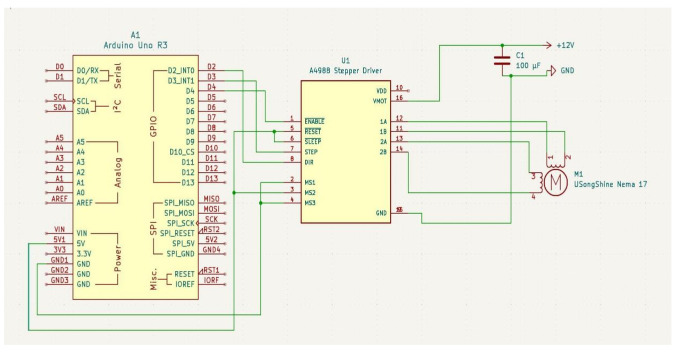

Figure 3 Turntable Schematic

Software Approach

- **Capture Module:** Acquires **RGBD data** from RealSense camera with intrinsic calibration
- **Filter Module:** Processes data through depth filtering, plane-based filtering, and point cloud optimization
- **Alignment Module:** Registers multiple views through feature matching and transformation calculation to build complete 3D model
- **Meshing Module**:
  - Load point cloud data from RGB-D capture as the reconstruction input.
  - Estimate per-point surface normals to capture local geometric structure.
  - Align normals across the surface to ensure correct mesh topology during reconstruction.
  - Apply **Poisson or Ball Pivoting surface reconstruction** to generate a 3D mesh from the oriented point cloud.

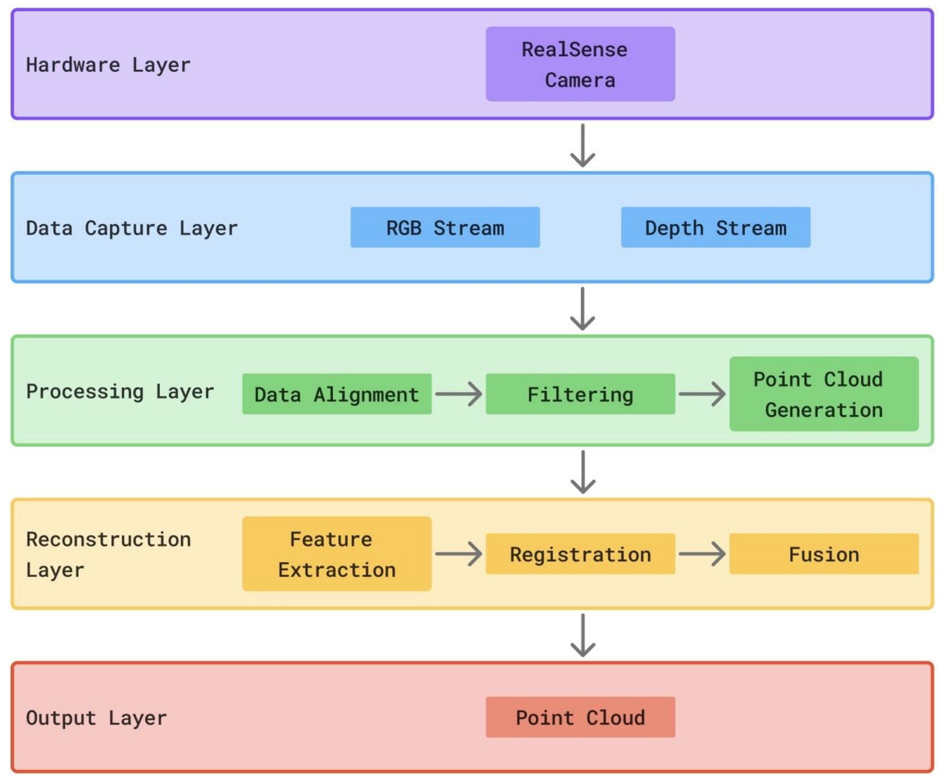

Figure 4: Point Clouds Workflow

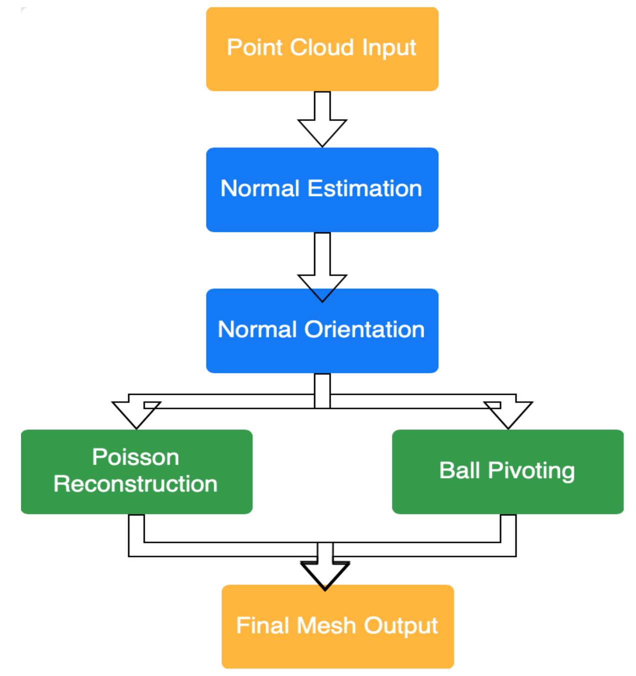

Figure 5: Meshing Structure

ROS2 Integration

- Designed a modular **ROS2 pipeline** to manage communication between hardware and software components.
- Integrated each module with a custom API wrapped in a ROS2 node, enabling seamless interaction and future scalability.

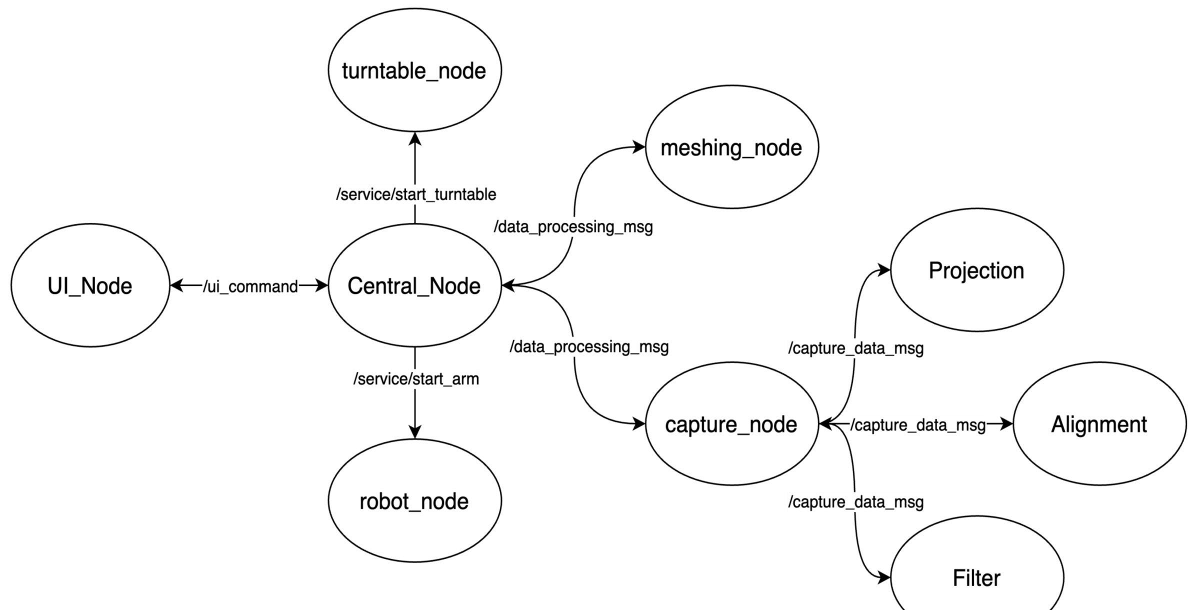

Figure 6: ROS2 Topic Map

Results

- **Robotic Arm:**
  - The XArm6 executed smooth, repeatable scanning trajectories under ROS 2 control, with consistent end-effector positioning and no motion interruptions.
  - Turntable rotation remained stable throughout all 360° sequences, requiring no manual intervention.
- **Point Cloud:**
  - Applied edge-preserving filters to reduce noise.
  - Aligned scans using **PnP** followed by **ICP.**
- **Meshing:**
  - Poisson reconstruction produced smooth, watertight meshes free of holes.
  - Ball-Pivoting reconstruction captured crisp detail at edges and corners, yielding models immediately suitable for 3D printing and inspection.

Figure 7: Actual Object

Figure 8: Depth Object

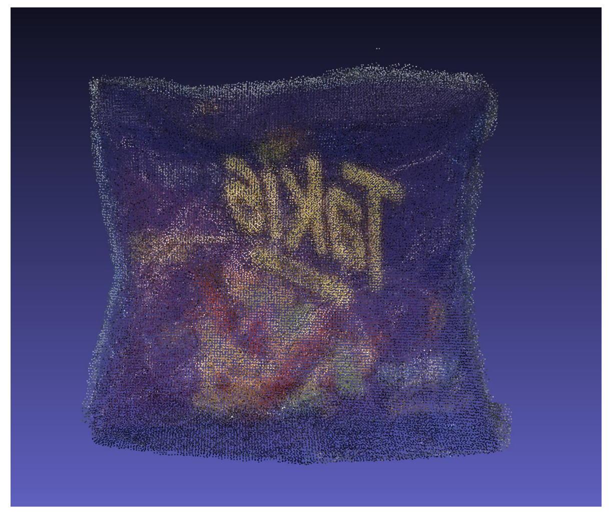

Figure 9: Point Clouds

Figure 10: Meshing Results

Future Work and Acknowledgments

- Upgrade to higher-resolution or global-shutter RGB-D cameras.
- Fuse LiDAR or stereo rig data to enhance point-cloud density.
- Integrate neural-implicit or TSDF-based volumetric reconstruction.
- Enable real-time intrinsic/extrinsic calibration and noise suppression.
- Coordinate multiple robotic arms for concurrent multi-view scanning.

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