Overview:

The implemented system detects screws on an EV battery pack using RGB images and point clouds captured by a Zivid 2+ camera. The goal is to estimate the 3D position and orientation of each screw relative to the camera and transform these poses into the robot's coordinate system for disassembly.

Methodology:

1. 2D Screw Detection:

The algorithm begins by detecting screw heads in a 2D image using the Hough Circle Transform. This method is efficient for detecting circular objects but is sensitive to noise and variations in lighting. Trade-offs include potential false positives (detecting non-screw objects) and false negatives (missing actual screws) due to image quality or occlusion. Preprocessing steps (grayscale conversion, adaptive thresholding, and morphological operations) aim to mitigate these issues.

2. 3D Screw Position Estimation:

Once 2D screw locations are identified, their 3D positions are estimated using the corresponding point cloud. For each detected screw, the algorithm finds the nearest point in the 3D point cloud based on the projected 2D location. The Z-coordinate of this nearest neighbour is used along with the 2D screw location and camera intrinsics to back-project the screw's 3D position in the camera coordinate system. A trade-off is that inaccuracies in the point cloud or incorrect depth estimation can lead to significant errors in the 3D position.

3. Intrinsic parameters:

Assumptions in Intrinsic Parameter Calculation

-*No Physical Calibration*: Intrinsic parameters are estimated solely from Zivid 2+ documentation.

-*Pinhole Camera Model:* Lens distortions are ignored.

-*Fixed Focus Distance:* Assumed to be exactly 1100 mm.

-*Accurate FoV:* Assumed 1090 mm × 850 mm at 1100 mm is precise.

-*Principal Point Centered:* Assumed at (image width/2, image height/2).

-*Linear Focal Length Computation:* Based on image size, focus distance, and FoV.

3. Screw Orientation Estimation:

Screw orientation is estimated using Principal Component Analysis (PCA) on a local neighbourhood of points around the estimated 3D screw position. PCA determines the principal direction of the point cloud in the neighbourhood, which is used as an approximation of the screw's orientation. This method is computationally efficient but assumes a relatively uniform distribution of points around the screw head. Trade-offs include sensitivity to noise and the choice of neighbourhood size; a smaller neighbourhood might be more accurate but more susceptible to noise, while a larger neighbourhood might be more robust but less precise.

4. Transformation to Robot Frame:

Finally, the estimated screw positions and orientations in the camera frame are transformed into the robot coordinate system using a provided transformation matrix. This step assumes the accuracy of the transformation matrix. Errors in the transformation matrix will directly affect the accuracy of the final screw poses in the robot frame.

5. Visualization:

The results are visualized using Open3D, showing the point cloud and the detected screws with their estimated positions and orientations. A 2D visualization highlighting the detected screw circles on the input image is also generated.

Overall Trade-offs:

The algorithm prioritizes computational efficiency over absolute accuracy. The use of the Hough Transform and nearest-neighbor search for 3D position estimation are computationally inexpensive but can be susceptible to noise and inaccuracies in the input data. The PCA-based orientation estimation is also efficient but relies on assumptions about point cloud density and uniformity. Future improvements could involve more robust feature detection methods, more sophisticated depth estimation techniques, and error analysis to quantify the uncertainty in the estimated screw poses.

Results:

Provided the output for Battery Pack 2, consisting of the following three files for each camera snapshot

- <name>_2d_detections.png – Displays screw detections on the image using OpenCV-based techniques.
- <name>_screw_positions.json – Contains the 3D pose (position and orientation) of each screw relative to the camera and transformed into the robot coordinate system.
- <name>_visualization.png – A rendered 3D visualization of the detected screws overlaid on the point cloud snapshot.