1. **PATH GENERATION**

**Transformation of Seam Points**

Consider a pointcloud set for located along the weld seam as described by the example application and defined in the CAD model. The weld seam exists at the shared location of the connecting faces of the two parts which make up the workpiece. The pointcloud set is a subset of the pointcloud set which represents the workpiece.

The pointcloud set and are defined with respect to a frame {{part}} located on the workpiece.

To complete the desired operation the robot must carry the torch along the weld seam. The path generation stage requires the robot tool path points to be described with respect to the fixed frame of the robot. The pointcloud sets and can be projected into the fixed frame of the robot with the rigid transformation for resulting from the ICP routine described previously as it is the best available approximation of the workpiece pose.

The set of points for is found by applying the rotation and translation separately as shown. = fn(R, t)

for

**Joint Velocity Profile Generation**

Canfield will add path generation here.

1. **IMPLEMENTATION USING ROS AND PCL**

This research has been implemented in ROS on Ubuntu Linux which provides a multi-threaded and distributed software framework for robotics applications.

The combination of 2D LiDAR scans into 3D pointclouds was done using a custom ROS package *scan2cloud* that is based on *ROS* *laser\_geometry*. The rigid transformation from the sensor frame to the base of the robot is programmed with *ROS tf* so that individual 2D scans collected using *ROS rplidar* can be processed and saved as a .pcd file with respect to a global origin.

The .pcd file is used for permanent storage and several pointcloud data types

The robot and sensor are operated simultaneously using ROS, and the resulting pointcloud is saved as a .pcd file which can be processed using the Point Cloud Library or converted to a .ply polygon file.

1. **MANUFACTURING APPLICATION**

A manufacturing task is considered, in which a weldment is performed on a workpiece resting on a welding table. The workpiece in this task consists of multiple components to be joined through weldment. The relative alignment of the multiple components of the workpiece is assumed to be correct within the physical constraints of the designed part prior to the automated process. In practice, this alignment is set by the operator and secured using clamps or other fixtures.

Variation in surface quality and workpiece dimension and shape are likely present however these are not the focus of this process. The workpiece geometries are generally assumed to match those in the model within a working tolerance. These local model inaccuracies certainly affect the global information produced regarding the geometry and location of the weld, but these affects are minor.

Two example applications are considered. In the first of which, two square tubes are joined perpendicular to one another with a fillet weld along two of the shared edges. In the second application, a square tube is joined to a flat plate with a fillet weld along the shared edge between the two components. In each of these examples, the assembly is temporarily joined together by clamps which will be included in the lidar scan. Prior to the alignment process, these clamps will be removed from the pointcloud data via segmentation with RANSAC.

In example application 1 the workpiece consists of two square tubes to be joined by weldment so that the tubes are perpendicular and form a tee.

In example application 2 the workpiece consists of a square tube to be joined by weldment to a flat plate so that the tube is perpendicular to the plate.

1. **SIMULATION RESULTS**

Example application A and B were performed for testing and validation of the proposed approach using synthetic data generated from CAD models of the workspace including the table and clamps as shown in the figure above. The models of the scene were converted to pointclouds using the uniform sampling process described for the conversion of the source cloud.