**Automated Weld Path Generation Using Iterative Closest Point Model-Workpiece Registration**

Definitions:

**ICP – Iterative Closest Point –**

* “Reference” cloud ( Target ) is fixed
* “Source” is transformed to match reference
* The data association (step1) is the most expensive part. It can be done in different ways.
  + Closest Point (kd-Trees)
  + Normal Shooting
  + Closest Compatible Point
  + Projection Based
* The error metric can also be calculated in different ways.
  + Point-Point
  + Point-Plane
* There are also other variants.
  + Point subsets
  + Weighting correspondences
  + Data association
  + Outlier pair rejection
* Here is the basic ICP algorithm:
  1. For each point in the **source**, find the closest point in the **reference**.
  2. Estimate a transformation **T** using root mean squared minimization to best align each **source** point to its **corresponding** reference point found in step 1.
  3. Transform the **source** points using **T** from step 2.
  4. Back to step 1 (re-associate).

**Automated Weld Path Generation Using Random Sample Consensus and Iterative Closest Point Model-Workpiece Registration**

**Abstract**

Jobs performed by small to medium enterprises (SMEs) are infrequently automated due to high setup costs and lack of technical expertise needed for robot training, however productivity and worker safety can be improved in SMEs with the use automated tooling. In a traditional automated manufacturing environment, tasks such a welding or painting are accomplished through execution of pre-programmed tool motions which rely on the location and orientation of the workpiece to be fixed and known. The lack of this spatial information is typically treated through positioning of the workpiece with respect to the robot arm using jigs or fixtures which are costly in initial setup are not easily modified. Further, the resulting toolpath associated with a desired task is typically defined through manual teaching resulting in a path appropriate for an individual job. For this reason SMEs requiring variation in part geometry or arrangement are not commonly automated. This work presents a method for automated weld path generation for a 6DOF co-bot arm using random sample consensus (RANSAC) and iterative closest point (ICP) model-workpiece registration. A collection of algorithms is employed to register, or locate, or a pointcloud representing the workpiece in a pointcloud of the working environment collected by a LIDAR scanner located on the robot. Once the known is located with respect to a fixed frame an automated weld path generation routine is used to generate series of tool poses offline. A representative set of welding processes in which a cylinder or rectangular tube is joined to a flat plate through weldment is investigated and a physical implementation of the method is demonstrated using a 3D LIDAR mounted to a 6DOF co-bot carrying a MIG welding torch.

**Introduction**

Small to medium enterprises perform manufacturing tasks associated with relatively low part volume and increased variation in assembly geometry as compared to jobs performed in large scale manufacturing environments. This type of manufacturing operation is infrequently automated due to high setup costs, however productivity and worker safety can be improved in small to medium enterprises through the use of automated tooling.

In a traditional automated manufacturing environment, a task such a welding or painting is accomplished through execution of pre-programmed tool motions which rely on the location and orientation of the workpiece to be fixed and known with respect to a global coordinate system. The need for spatial information is typically treated through positioning of the workpiece with respect to the robot arm using jigs or fixtures which are costly in initial setup and are not easily modified. In large scale production environments, this can be accomplished with dedicated infrastructure built into the environment such as moving jigs on assembly lines and other features available in a highly structured environment. Further, the resulting toolpath associated with a desired task is typically defined through manual teaching resulting in a path appropriate for an individual job.

For this reason SMEs requiring variation in part geometry or arrangement are not commonly automated. This work presents a method for automated weld path generation for a 6DOF co-bot arm using random sample consensus (RANSAC) and iterative closest point (ICP) model-workpiece registration. A collection of algorithms is employed to locate, or register, a pointcloud representing the workpeice in a pointcloud of the working environment collected by a LIDAR scanner located on the robot. Once the known part can be located with respect to a fixed frame an automated weld path generation routine is used to plan a weld toolpath offline. A representative set of welding processes in which a cylinder or rectangular tube if joined to a flat plate through weldment is investigated and a physical implementation of the method is demonstrated using a 3D LIDAR mounted to a 6DOF co-bot carrying a MIG welding torch.

As technology advances humans and robots must adapt to remain relevant in our respective environments and we are currently seeing this in the emergence of the co-bot workcell paradigm.

**Description of Process**

A fillet weld in which a circular or rectangular tube is joined to a flat plate is considered. The two workpieces, the required weldment, and the working environment are modeled as well the 6DOF co-bot which sits in the center of a planar welding table.

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.

The automated weld path generation method consists of a sensing stage, an offline model registration stage, followed by the path generation stage.

Prior to the sensing stage the two workpieces are manually placed in the robot workspace in the proper relative orientation to be joined by a weldment. The relative orientation of the parts must match that of the model to an extent and the global location of the workpieces is restricted to the usable workspace of the robot.

In the scanning stage a sweeping motion of the arm is performed, and the workpiece and environment are scanned with the 2D lidar mounted linkX of the robot. Multiple 2D lidar scans are measured along with corresponding sensor poses at (linkS). As the scanning stage continues the 2D lidar scans are transformed from the sensor frame linkS to the base frame link0 through the robot forward kinematics and accumulated into a 3D pointcloud with respect to the base frame. By nature, 3D lidar produces large sparse and redundant data sets. Therefore, the scans are filtered and reduced to the usable workspace to improve results and lower the computational requirements of stages of this process. This 3D scan of the workspace is saved as the reference cloud.

Prior to the model registration stage, an ideal model of the joined workpieces including the weldment, and environment is generated using CAD. The models of the workpieces alone are used to generate two separate source pointclouds with respect to their individual local frames. In the model registration stage, the source clouds derived from CAD are compared to the reference cloud acquired from lidar in the sensing stage. The relative transformation between clouds is found using the iterative closest point algorithm (ICP). The pose of the two parts can be used to determine the required location of the weld seam in a global sense.

The geometry and location of the desired weld seam in the workspace is required for offline generation of an appropriate toolpath. This information is determined by measuring the pose of the two individual workpieces with respect to a frame fixed to the robot base. Once this is information is known the appropriate toolpath can be generated. Determination of the poses of the individual workpieces represents to majority of this work and the method is described in detail.

**The Approach – RANSAC + ICP Model-Workpiece Registration**

1. SCANNING STAGE - A **reference** pointcloud is generated from multiple 2D LIDAR scans taken at known robot poses – This is a relatively large, sparse Pointcloud. Name: ‘cloud\_lidar’
2. PRE-FILTERING STAGE - The ‘cloud\_lidar’ or **reference** is reduced or ‘cropped’ to a region inside of the usable workspace of the robot. This reduces computation during the subsequent routines by removing unneeded data generated during the scanning stage.
3. SOURCE GENERATION - A **source** pointcloud is generated using CAD software. This results in a relatively small cloud with controlled resolution and an ideal representation of both parts including the weldment. Name: ‘cloud\_cad’

Each component of the assembly is generated as a part in CAD and exported to a polygon image format (.ply) and then is converted to a pointcloud file (.pcd). Similarly a cloud of the entire assembly is stored. A model of the working environment (welding table) is not included however, the fact that the table is planar and exists below the work piece is useful information.

1. REGISTRATION STAGE – Each component in the assembly is registered, or located, individually within the lidar cloud resulting in a transformation matrix from each individual **source** cloud to the single **reference** cloud. These transformations contain to poses of each part.

Registration of an individual component is accomplished with a combination of RANSAC segmentation followed by ICP registration. Note: ICP performs when ‘association’ between clouds is possible. This implies that the clouds should be similar is size(?)

1. PRE ASSOCIATION RANSAC – Random Sample Consensus + Segmentation – is used to determine which points in the **reference** model could be associated with the **source**. Separate points in reference into two categories, cylinder points and non-cylinder points. This is particularly effective in separating the two components of an assembly associated with a weld in which a cylinder is joined to a flat plate.
2. REGRISTRATION ICP – Iterative Closest Point is used to find a transformation representing the location and orientation of a part in the lidar cloud. This relies on the fact that the source cloud for each part was generated with respect to a the fixed frame.
3. PATH GENERATION – Once a spatial description of the working environment has been constructed the desired toolpath can be pre-programmed offline.

**And here is the math…**

Reference clouds from CAD for each piece of the model (Part1, Part2, … )

Source cloud is generated from 2D lidar scans and end effector poses.

The ‘Generalized ICP’ Algorithm is used to align reference and source clouds. This results in a transformation for each part. This is based on a ‘root-mean squared’ minimization.

Minimize E, find a rotation R and a translation t (T) that minimize E.

Transformation from source to reference of part1

Transformation from source to reference of part2

**Results**

General Notes

* This approach provides a benefit over classical online seam tracking in that it does not require measuring the joint itself.
* It is important to distinguish between ‘assembly variations’ and ‘form variations’
* This process could be extended and used to check for unacceptable workpiece geometries and or relative placement.
* The ability to locate objects in the working environment could also be used to assist the operator in workpiece placement as in [] where a laser projector is used to provide a visual guide for manual placement of the workpiece prior to weldment.
* The group at ‘Fraunhofer’ then uses the transformations to update the reference models…
* Rajaraman Dawson-Haggerty Shimada Bourne use a ‘laser projector’ to help the operator in ‘placement’ of the workpeice. ‘robot guided placement procedure’ + ‘3d sensing for preplanned tool paths’

Bibliography

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Automated workpiece localization for robotic welding

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A method for registration of 3D shapes

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