Object Reconstruction with ICP

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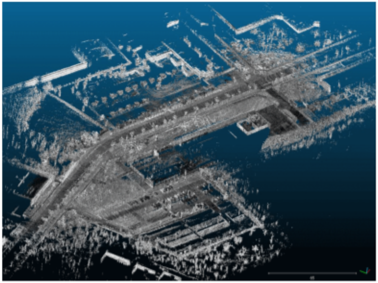
What is Object Reconstruction

Object Reconstruction is the process of building a model/representation of an object or an environment using sensor data.

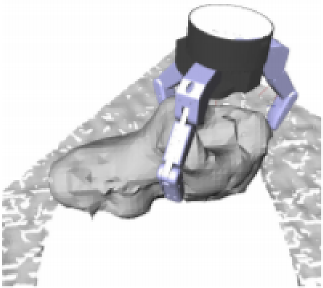
- Enviroments/Maps for localisation



Source: LiDAR point clouds correction acquired from a moving car based on CAN-bus data[11]

What is Object Reconstruction

- 3D models for grasp planning

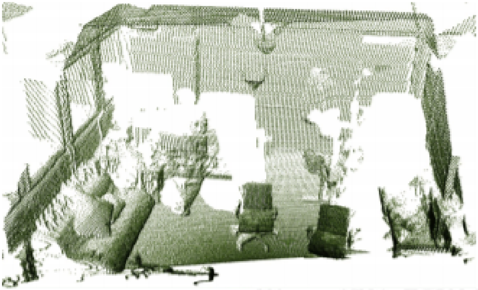


Source: Shape Completion Enabled Robotic Grasping[13]

- CAD

Point Clouds

- Set of points in 3D-space
- Can include color
- Usually obtained by RGB-D Cameras, LIDAR or stereo-vision systems



Source: 3D is here: Point Cloud Library (PCL)[12]

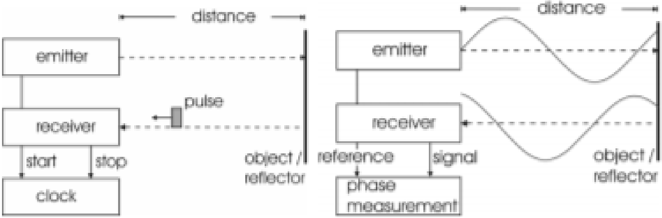
RGB-D Cameras

- Time of flight
- Structured light
- Both active sensors
- Relatively cheap consumer product (Kinect) available

Source: Microsoft Kinect Sensor and Its Effect[14]

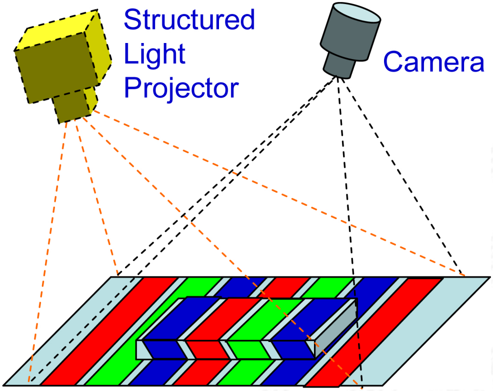
Time of flight

- Measure the delay of an light-pulse
- Measure the shift in phase



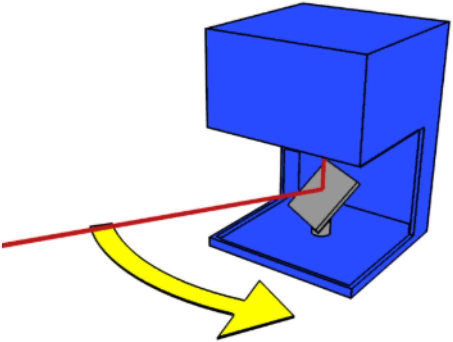
Source: Calibration for Increased Accuracy of the Range Imaging Camera Swissranger[8]

Structured Light



Source: Structured-light 3D surface imaging: a tutorial [5]

- **L**ight **D**etection **A**nd **R**anging



Source: https://en.wikipedia.org/wiki/Lidar[1]

Stereo Vision

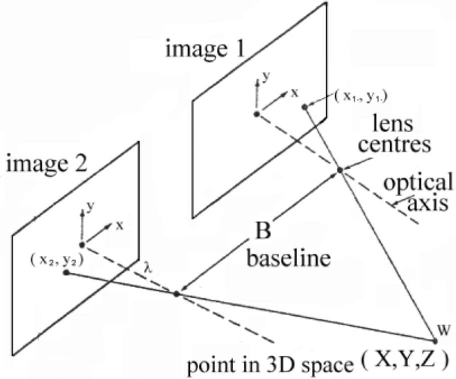


Figure 2. Stereo image geometric model.

Source: Performance evaluation of 3D computer vision techniques[7]

Point registration

- Let A and B be point clouds with corresponding points
- A point registration is a rotation and a translation, which transform B onto A
- Correspondents unknown for object reconstruction
- Commonly used algorithm: **I**terative **C**losest **P**oint algorithm (ICP)

ICP-Algorithm

- Assumption: Point clouds already close to the right position
- Step 1. Assign every point of point cloud B to the closest point of A
- Least squares error: $\frac{1}{N}\sum_{i=1}^{N}\|\hat{a}_i - b_i\|^2$
- Step 2. Find a Rotation R and a Translation T such that the error is minimal

$$\frac{1}{N}\sum_{i=1}^{N}\|\hat{a}_i - R(b_i) + T\|^2$$

ICP-Algorithm

- The translation is trivial
- Calculate the center of mass of the assigned Points $\hat{A}$ and B and subtract them

$$c_{\hat{A}} = \frac{1}{N_{\hat{A}}} \sum_{\hat{a} \in \hat{A}} \hat{a}, c_B = \frac{1}{N_B} \sum_{b \in B} b$$

$$T = c_B - c_{\hat{A}}$$

- Rotation can be solved by singular value decomposition (SVD)
- Calculate the sum of all outer products between the point pairs in the frame of their center of mass

$$H = \sum_{i=1}^{N} b\prime_i \hat{a}\prime_i^T$$

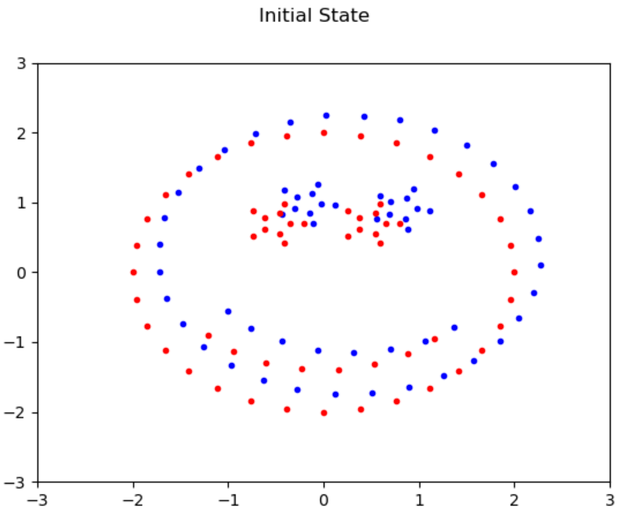
- Compute the SVD of H

$$H = U \Lambda V^T$$

- Compute the rotation from the decomposition

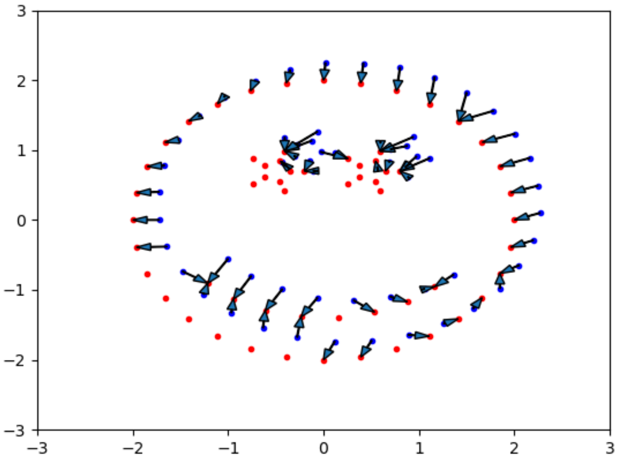
$$R = VU^T$$

ICP-Algorithm - Step by Step

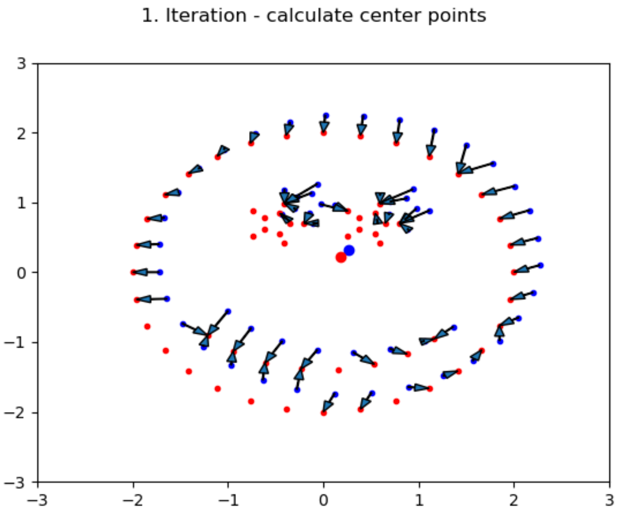


ICP-Algorithm - Step by Step

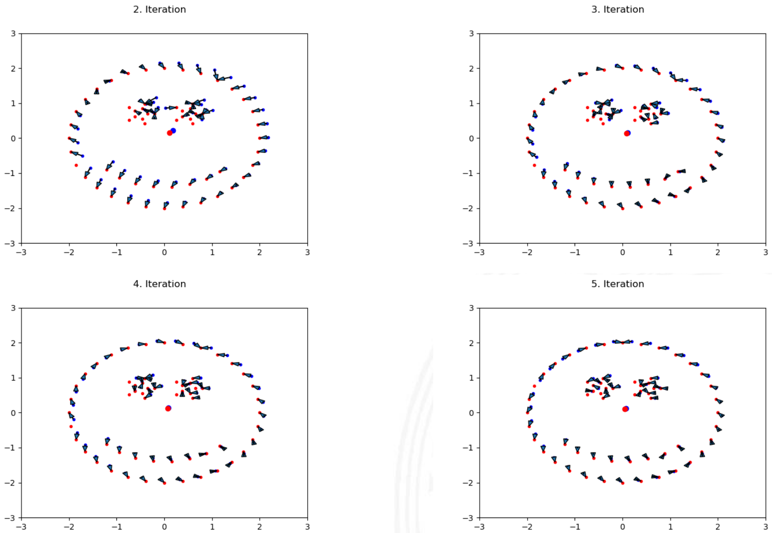
1. Iteration - Find closest points



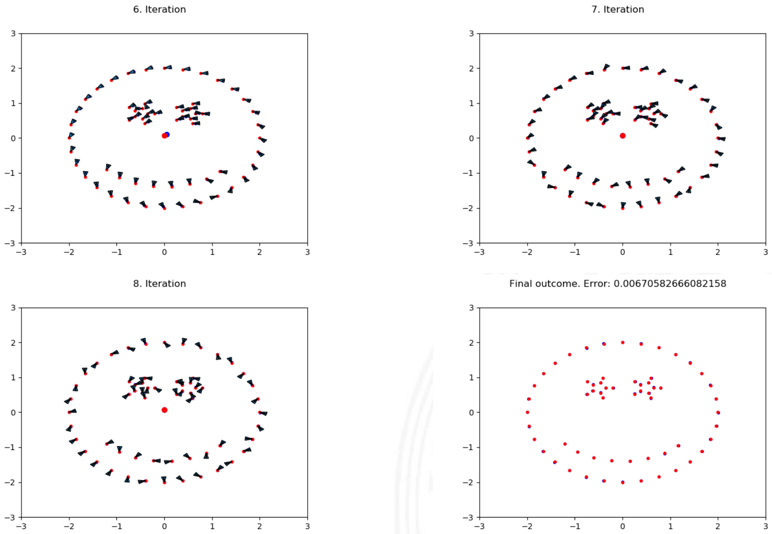
ICP-Algorithm - Step by Step



ICP-Algorithm - Step by Step



ICP-Algorithm - Step by Step



ICP-Algorithm

while *distance* $> \delta$ *or error not converges* **do**
    FindClosestPoints;
    ComputeRegistration;
    ApplyRegistration;
end

Algorithm 1: ICP-Pseudocode

ICP-Algorithm

- Remember: The assumption was point clouds are already close to each other
  - Pre-align them with prior knowledge
    - i.g. Difference between the camera location
  - Use sparse feature detection to find corresponding points
- Remove the matched points with the highest distance (TrICP) to remove outliers
- Improve point matching by including RGB data

Object Reconstruction

1. View planning
2. Obtain point cloud data
3. Pre-align point clouds
4. Register point cloud using ICP
5. Combine the point clouds and do some clean-up
6. Repeat until the object or environment is sufficiently reconstructed

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