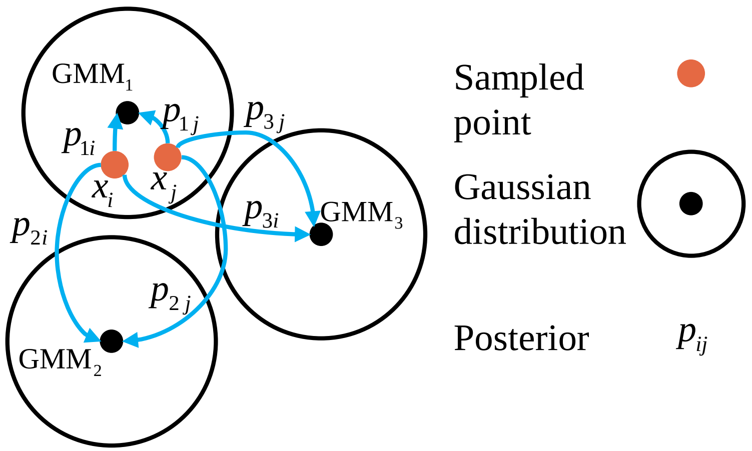
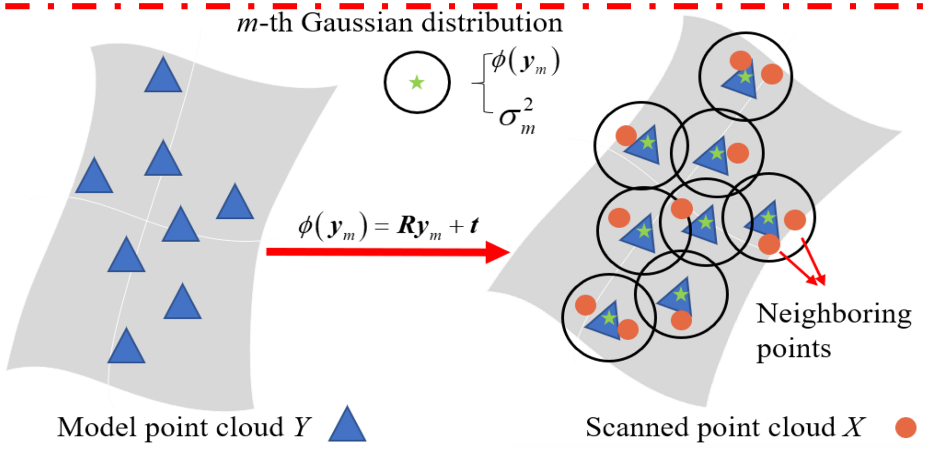
Probability-based Point Cloud Registration

- Model data is treated as centers of Gaussian Mixture Model (GMM) and scanned data is treated as sampled points from model. The registration problem is casted as a model-fitting one. Local Consistent constraint is incorporated to improve robustness and accuracy.



- Posterior: represents the correspondences
- LC: restrain the posterior distribution between neighboring points to improve robustness
- KL-Divergence: measure the similarity of two posterior distribution

$$D\left(p(z_i \mid x_i) \,\|\, p(z_j \mid x_j)\right) = \sum_{m=1}^{M+1} p(z_{im} \mid x_i) \log \frac{p(z_{im} \mid x_i)}{p(z_{jm} \mid x_j)}.$$

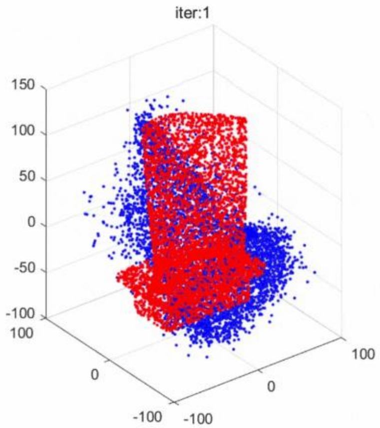


Objective function:

$$Q(\Theta) = Q_{\mathrm{GMM}}(\Theta \mid \Theta^{\mathrm{old}}) + \lambda Q_{\mathrm{LC}}$$

$$Q_{\mathrm{LC}} = \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} D_{ij}$$

$$Q_{\mathrm{GMM}}(\Theta \mid X, \mathcal{Z}) = E_{\mathcal{Z}}\left[\log P(X, \mathcal{Z}; \Theta \mid X)\right].$$



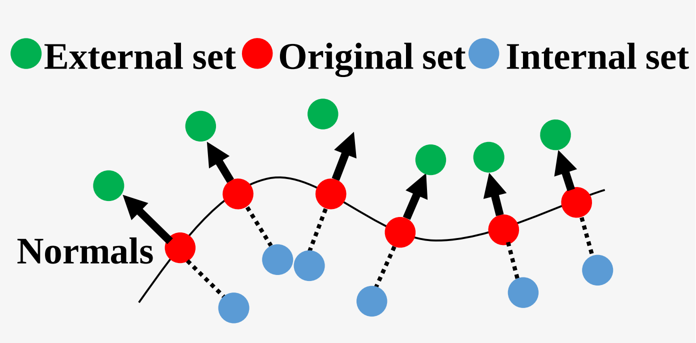
Ongoing task: extending the method to joint registration

L. Su, W. Xu, and W. Li, “Robust point cloud registration in robotic inspection with locally consistent gaussian mixture model,” *IEEE Trans. Instrum. Meas.*, 2024, Major Revisions.

Surface Reconstruction and Mesh Filtering

- Implicit B-spline (IBS) function is used to represent the surface, which is fitted with 3L algorithm. Marching cubes method is employed to generate mesh data and an anisotropic bilateral filtering method is designed to denoise the mesh data.

Implicit B-spline function: $f(\boldsymbol{p}) = \sum_{i,j,k} c_{i,j,k} B_i(x) B_j(y) B_k(z)$

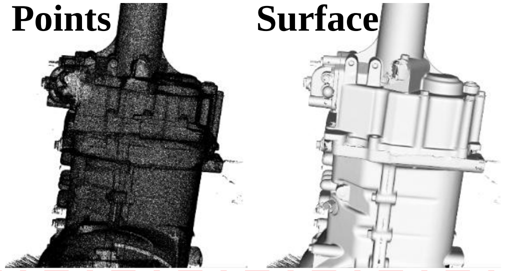


3L: offset original data along normal direction to guarantee the surface orientation

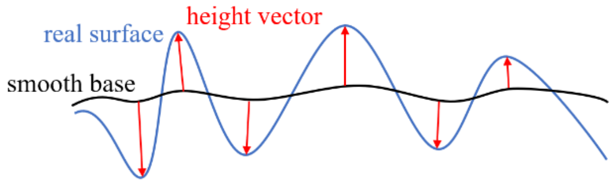
Objective function: $E(c) = \left\| M_{3L} c - b \right\|^2, \; M_{3L} = \begin{bmatrix} M_{+\sigma} \\ M_0 \\ M_{-\sigma} \end{bmatrix}, \; b = \begin{bmatrix} +\varepsilon \\ 0 \\ -\varepsilon \end{bmatrix}$

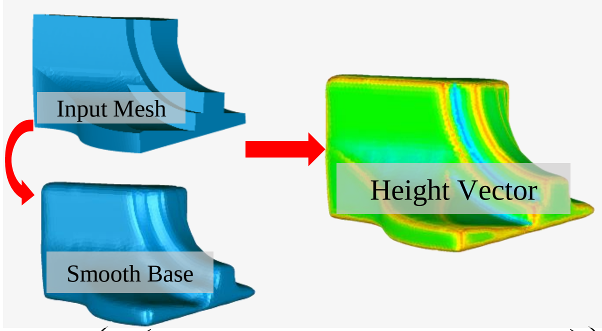
Global tension constraint:

$T(c) = \int_V \left\| Hf(\boldsymbol{p}) \right\|^2 d\boldsymbol{p}$



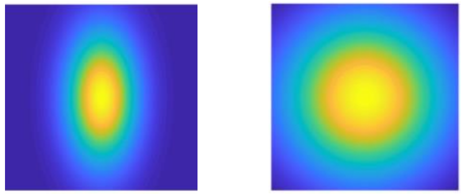
Height vector field:





Anisotropic Gaussian Kernel: $K(\boldsymbol{\delta}) = \exp\left(-\left(\frac{(\boldsymbol{\delta}^{\mathrm{T}}\boldsymbol{u}_1)^2}{\gamma\lambda_1} + \frac{(\boldsymbol{\delta}^{\mathrm{T}}\boldsymbol{u}_1)^2}{\gamma\lambda_2} + \frac{(\boldsymbol{\delta}^{\mathrm{T}}\boldsymbol{u}_1)^2}{\gamma\lambda_3}\right)\right)$

- Absolute distance
- Diffusion situation



Updated height vector:

$$\boldsymbol{v}_i' = \frac{\sum_{j=1}^{N_i} \alpha_j K_{si}(\boldsymbol{c}_j, \boldsymbol{p}_i) K_{vi}(\boldsymbol{v}_j, \boldsymbol{v}_i) \boldsymbol{v}_j}{\sum_{j=1}^{N_i} \alpha_j K_{si}(\boldsymbol{c}_j, \boldsymbol{p}_i) K_{vi}(\boldsymbol{v}_j, \boldsymbol{v}_i)}$$

$K_{si}(\boldsymbol{c}_j, \boldsymbol{p}_i)$: smooth mesh surface

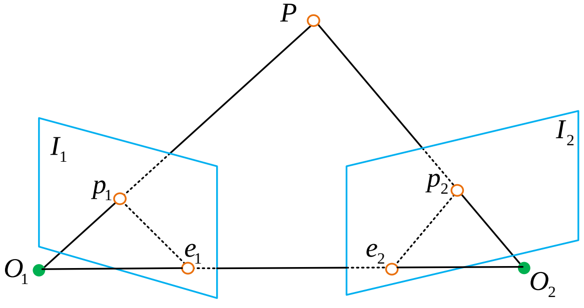
$K_{vi}(\boldsymbol{v}_j, \boldsymbol{v}_i)$: preserve mesh feature

L. Su et al., “An adaptive anisotropic bilateral filtering method for mesh data in scale space,” *Meas. Sci. Technol.*, vol 35, no. 6, 2024, doi: 10.1088/1361-6501/ad317e

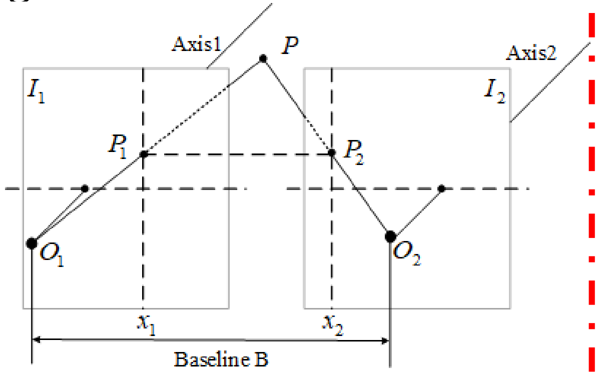
Integration of Multi-View Point Cloud In Robotic Measurement

- The centers of marked points is extracted and matched to coarsely register coordinates under different views. Then, the poses are refined though graph optimization with g2o framework.

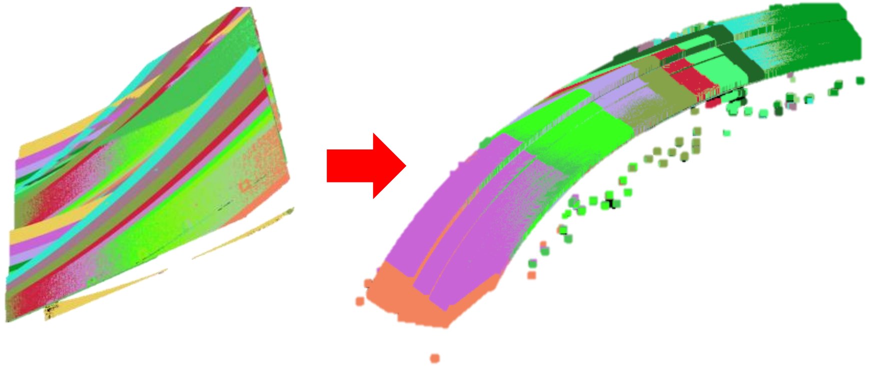
3D coordinate reconstruction of marked points with stereo images



Polar constraints



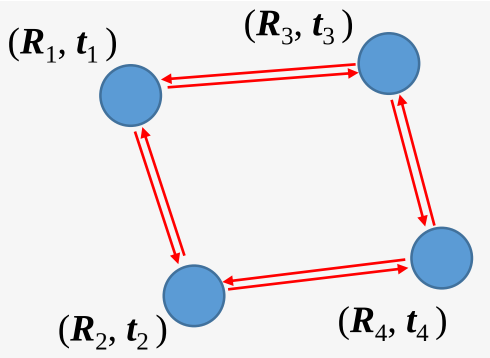
Stereo camera model



Registration of measured data

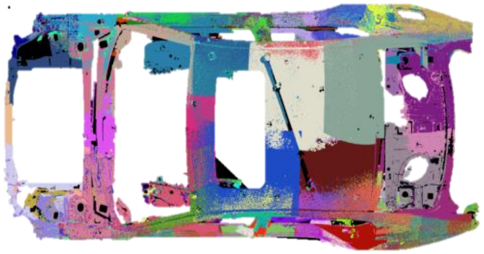
Optimization Function:

$$E(\boldsymbol{R},\boldsymbol{t}) = \frac{1}{N_{corr}} \sum_{\substack{m,n=1 \\ m\neq n}}^{K} \sum_{i=1}^{N_{mn}} \left\| (\boldsymbol{R}_m \boldsymbol{p}_m^i + \boldsymbol{t}_m) - (\boldsymbol{R}_n \boldsymbol{p}_n^i + \boldsymbol{t}_n) \right\|^2$$



- Node: transformation matrix of each point cloud
- Edge: sum of distances between correspondence points

Before Optimization



After Optimization