DTU Informatics
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# Evaluation of surface registration algorithms for PET motion correction

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**Research is ongoing to perform motion correction for high resolution PET using structured light and 3D surface registration [1]. Variants of the Iterative Closest Point algorithm were compared to non linear optimization.**

### The ICP algorithm

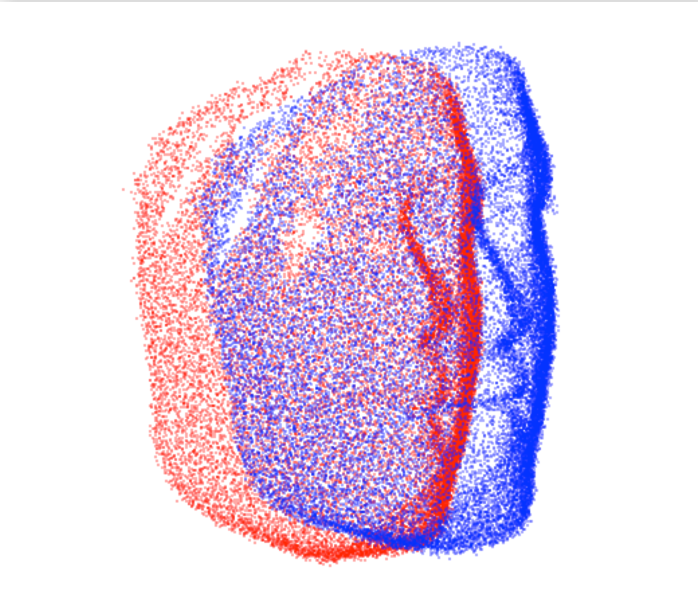
In order to address the issue of point correspondence, the ICP algorithm [1,2] iteratively performs the following steps

1. Matching: for every data point the nearest model point neighbor in found.
2. Minimization: the error metric is minimized.
3. Transformation: data points are transformed using the result of step 2.

A taxonomy of ICP variants was established by Rusinkiewicz and Levoy [2]. It identifies six distinct stages of the algorithm:

1. Sampling
2. Matching
3. Weighting
4. Rejecting
5. Error metrics
6. Minimization of error metric

We have investigated on these stages and determined which were most suitable for surface registration of human face point clouds. The test scene was transformed rigidly into a second point cloud such that point correspondence was known. Performance was then evaluated on the RMS error of real point pairs.



Test scene: a point cloud of a human face with app. 20 k points. Gaussian noise was added independently to model and data.

### Sampling

One tenth of points were sampled using the following sampling strategies:

- Uniform and random sampling generally reduce computational complexity and yield better convergence
- Normal-space has different normal directions represented as uniformly as possible and represents a simply form of feature extraction
- Curvature-space sampling samples among different surface curvature values. Curvature might be estimated efficiently as the ratio of smallest to sum of eigenvalues in a PCA framework.

### Weighting

Different weights might be assigned to point pairs in the objective function. Considering a pair $(p, q)$ :

- Normal compatibility weighting using the weight [2]

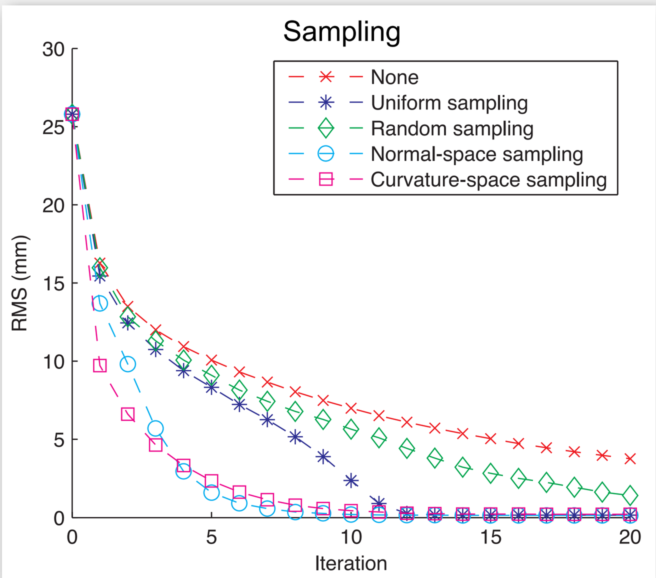
$$w = \vec{n}_p \cdot \vec{n}_q$$

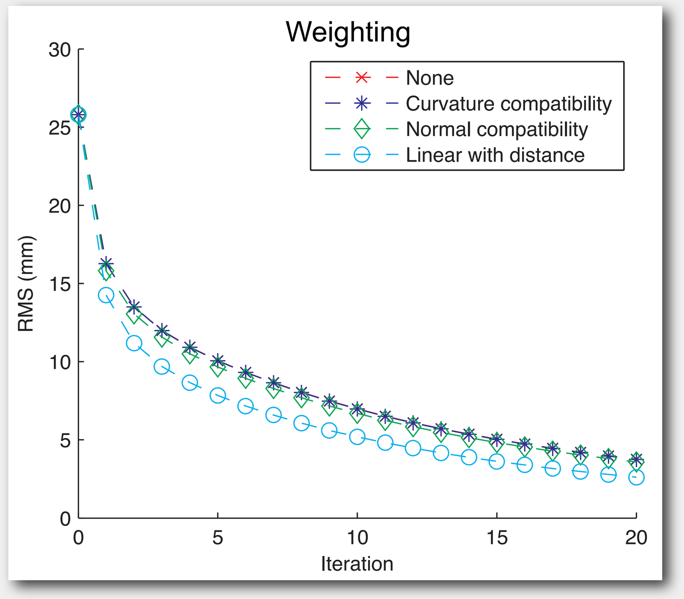
- Curvature weighting based on normalized curvature values

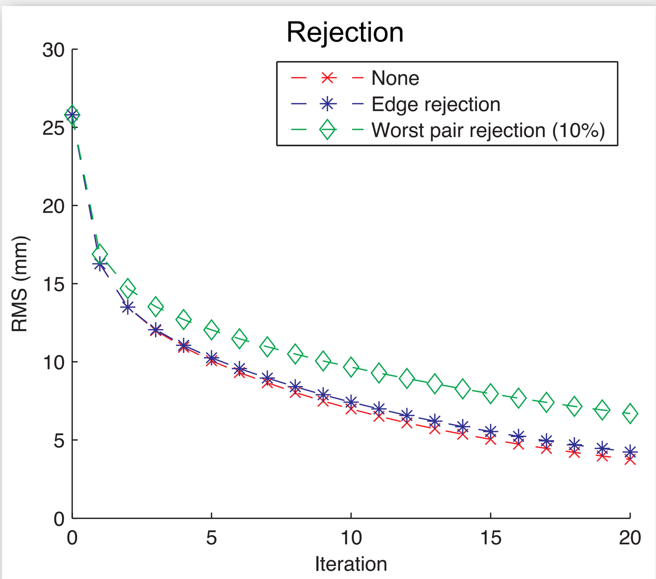
$$w = \mathrm{e}^{-(c_p - c_q)^2}$$

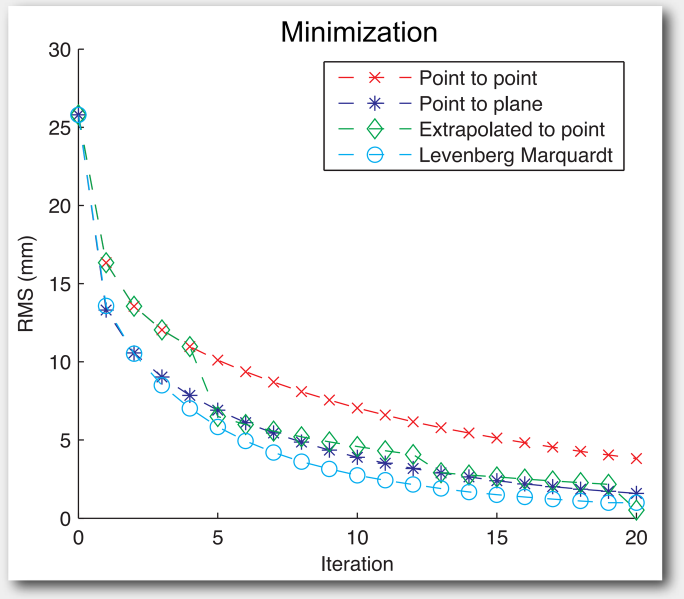
- To weight point pairs according to their distance [5]

$$w = 1 - \frac{\mathrm{dist}(p,q)}{\mathrm{dist}_{\mathrm{max}}}$$



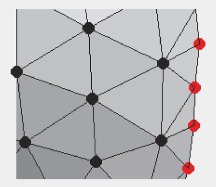




### Rejection

Point pairs may be rejected based on their distance or compatibility in some sense.

- *Winsorising*: the 10% of pairs with greatest distance are rejected.
- Point pairs involving *edge vertices* might be rejected.



Edge rejection: points defining an edge of a triangulated surface are considered edge vertices if that edge is part of only one triangle.

Real data is likely to have partial overlap and both rejection methods will give greater advantages.

### Minimization

The objective function might be stated as follows:

- Point to point minimization:

$$E = \sum_{i=1}^{N} \|\mathbf{R}p_i + \vec{T} - q_i\|^2$$

- Point to plane minimization:

$$E = \sum_{i=1}^{N} \left[ \left( \mathbf{R}p_i + \vec{T} - q_i \right) \cdot \vec{n}_i \right]^2$$

These are compared to classical minimization using the *Levenberg-Marquardt* algorithm, which surprisingly proved to be more than competitive (computation times are worse).

Very good results were achieved when combining the ICP algorithm with extrapolation between iterations [3].

### Conclusion

Tweaking the general ICP algorithm pays off if done properly.

[1] PhD study carried out by Oline Vinter Olesen, DTU IMM, Rigshospitalet Denmark and Siemens Healthcare AS.
[2] S. Rusinkiewicz and M. Levoy. Efficient variants of the icp algorithm. Proceedings Third International Conference on 3-D Digital Imaging and Modeling, pages 145–152, 2001.
[3] P.J. Besl and H.D. McKay. A method for registration of 3-d shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence, 14(2):239–256, 1992.
[4] Y. Chen and G. Medioni. Object modeling by registration of multiple range images. Proceedings. 1991 IEEE International Conference on Robotics and Automation, 1991.
[5] G. Godin, M. Rioux, and R. Baribeau. Three-dimensional registration using range and intensity information. Proceedings of the SPIE, 2350:279–290, 1994.