LAPLACIAN EIGENMAPS FOR MULTIMODAL GROUPWISE IMAGE REGISTRATION

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Objective

Recently, interest has grown for unbiased groupwise registration in image processing tasks such as:

- Population analyses
- Atlas construction
- Perfusion analyses
- Radiotherapy planning
- Multiparametric MRI
- Longitudinal treatment follow-up

Registration of multiple multimodal images can be challenging since state-of-the-art multimodal pairwise metrics based on mutual information cannot be easily extended to groupwise registration.

Materials & Methods

Dimensionality reduction in groupwise registration

Groupwise registration is defined as an optimization problem of $n$ transformations

$$\mu = \arg \min_\rho \left| f_1 \circ \rho, \ldots, f_n \circ \rho \right|, \quad (1)$$

Represent the $n$ images as features and each sampled coordinate as an observation in the $n$-dimensional image space. The assumption is made that the $n$-dimensional data can be reduced and that a better reduction corresponds to a better alignment.

Huijinga et al.[1] proposed to use PCA, a linear dimensionality reduction technique, in applications were a linear subspace can be assumed.

Proposed methodology

As such we propose to use Laplacian Eigenmaps[2], a non-linear dimensionality reduction technique, to alleviate these shortcomings. In the proposed methodology every sampled coordinate, $f_i$, is represented as a node in a graph and the adjacency or weight matrix is constructed following

$$W_{ab} = \begin{cases} 0 & \text{if a and b are not connected} \\ \exp(-|a - b|^2) & \text{if a and b are connected} \end{cases} \quad (2)$$

Hereafter the Laplacian and diagonal matrix are constructed and the eigenvalue problem is solved

$$L \mathbf{v} = \lambda \mathbf{D} \mathbf{v} \quad (3)$$

The proposed dissimilarity matrix is constructed to be the magnitude of the Fiedler eigenvalue or algebraic connectivity[3], the second smallest eigenvalue of the Laplacian matrix.

Synthetic Experiment

Two synthetic images (40x30 pixels) were constructed specifically to investigate the metric behavior of the proposed methodology in non-linear intensity relationships.

The experiment shows that the metric based on PCA predicts a maximum and thus a highly unfavorable alignment when no displacement is applied. The proposed methodology reveals a global minimum at the correct alignment of the images.

Clinical Experiments

Experiments were performed in two clinical datasets where the proposed methodology was compared to other state-of-the-art groupwise dissimilarity metrics and to a sequential pairwise approach using mutual information. The performance of the different dissimilarity metrics is evaluated using the groupwise target registration error (TRE).

Carotid MR

Eight image sequences were obtained under a gradient echo MRI sequence for different flip angles and TE preparation times. Five different acquisition settings were investigated for each image sequence.

RIRE

A total of 18 patients were included in the RIRE project[4] for which up to five acquisitions of the brain were performed. These acquisitions included CT, MR-T1, MR-T2, MR-PD and PET.

Results for Carotid MR

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean ± Stdev</th>
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<tbody>
<tr>
<td>MI</td>
<td>1.07 ± 0.44</td>
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<tr>
<td>PCA</td>
<td>1.15 ± 0.45</td>
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<tr>
<td>PCA2</td>
<td>1.10 ± 0.44</td>
</tr>
<tr>
<td>AMI</td>
<td>1.11 ± 0.44</td>
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Results for RIRE

<table>
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<tr>
<th>Method</th>
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<th>MisReg</th>
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<tbody>
<tr>
<td>MI</td>
<td>2.48 ± 0.82</td>
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<tr>
<td>PCA</td>
<td>4.94 ± 4.08</td>
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<tr>
<td>PCA2</td>
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<tr>
<td>LE</td>
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Conclusion

A novel dissimilarity metric for multimodal groupwise registration based on the non-linear dimensionality reduction technique, Laplacian eigenmaps, is proposed. Experiments show increased accuracy and robustness compared to other state-of-the-art groupwise registration methodologies.

References