INVERSION: A ROBUST METHOD FOR CO-REGISTRATION OF T1 AND DIFFUSION WEIGHTED MRI IMAGES

Chitresh Bhushan¹, Justin P. Haldar¹, Anand A. Joshi¹, David W. Shattuck², Richard M. Leahy¹

¹Signal and Image Processing Institute, University of Southern California, Los Angeles, CA, USA; ²Department of Neurology, University of California, Los Angeles, CA, USA

Introduction
- Co-registration of T1 and diffusion MRI images is required for multi-modal studies.
- Normalized Mutual Information (NMI)¹ & Correlation Ratio (CR)² have been commonly used for Inter-modal registration.
- CR & NMI are known to be non-convex and non-smooth, which can cause registration algorithms to converge to sub-optimal solutions³.
- We propose INVERSION (Inverse contrast Normalization for VERy Simple registraTION), which uses prior information about the image contrast in T1-weighted (T1w) and T2-weighted b=0 s/mm² (T2W-EPI) images for robust co-registration.

Method
- Contrast in a T1w brain image is approximately the inverse of the contrast in a T2W-EPI image (i.e., white matter > gray matter > CSF in a T1 image, while CSF > gray matter > white matter in a T2W-EPI image).
- INVERSION exploits this relationship to transform the intensities in T2W-EPI image to make it look like a T1w image.
- The transformation map between T1w image \( I_{T1} \) and T2W-EPI image \( I_{T2} \) is given by \( F(I_{T2}, I_{T1}) = f_{I_{T1}, I_{T2}}(1 - I_{T2}) \), where \( f_{I_{T1}, I_{T2}} \) is the histogram matching function.
- This transformation enables the use of simpler sum of squared differences (SSD) cost function for inter-modal image registration.

```
Intensity transformation map \( F(\cdot) \)
```

Fig 1. (Left) Intensity transformation map of a brain image. (Right) Slices from (i) the MPRAGE image, (ii) the inverted T2W-EPI image, and (iii) the original T2W-EPI image.

Materials
- Acquired MPRAGE, diffusion images (single-shot EPI, TE=115ms, TR=10s, 65 directions, b=2500s/mm², one b=0s/mm², 2x2x2mm³) and fieldmap.
- Corrected diffusion images for susceptibility induced distortion using the fieldmap⁴.
- Aligned MPRAGE to distortion corrected T2W-EPI image using manually guided registration⁵ to create the gold-standard aligned image pairs for further analysis.

Results – Cost function Behavior
- Studied change in different cost functions as images were misaligned (translation along the x-axis) and smoothened using Gaussian kernel.
- NMI and CR showed good behavior for small translations but both had relatively flat & noisy regions of the cost function at large translations, which can make optimization difficult.
- INVERSION showed the smoothest cost function and was convex over the translation range at all levels of the smoothing.
- The INVERSION cost function can be much easier to optimize numerically and can be more sensitive to misregistration over a broader range.

```
<table>
<thead>
<tr>
<th>Gaussian SD (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma = 0.0 )</td>
</tr>
<tr>
<td>( \sigma = 1.0 )</td>
</tr>
<tr>
<td>( \sigma = 2.0 )</td>
</tr>
<tr>
<td>( \sigma = 3.4 )</td>
</tr>
<tr>
<td>( \sigma = 5.0 )</td>
</tr>
<tr>
<td>( \sigma = 7.0 )</td>
</tr>
</tbody>
</table>
```

Fig 3. Behavior of different cost functions as a function of misalignment and smoothing.

```
Before alignment | After alignment
```

Fig 4. Example of a rigid registration using INVERSION. The T2W-EPI image is overlaid by edge maps from the MPRAGE image in red.

Results – Performance & Consistency
- We applied 54 known rigid transformations to the aligned MPRAGE image and assessed the RMS error⁶ of the registration achieved with each cost function.
- We studied registration results without any initialization and after matching the centroids of the image prior to registration.
- NMI and CR show good performance with small transformations but were not consistent and accurate for larger transformations.
- The proposed INVERSION method showed low RMS error and consistent behavior (RMS error of approx. 1 mm) across all applied transformations.

```
Performance without any initialization
```

Fig 2. Comparison of performance of different cost functions.

```
Performance with centroid initialization
```

References
2. Roche et al., MICCAI 1998; 1115-1124.
3. Jenkinson & Smith, Medical Image Analysis. 2001; 143-156
5. RView (http://rview.colin-studholme.net)

Grant Supports
NIH grants R01 EB009048, P41 EB015922 and R01 NS074980 and NSF grant CCF-1350563.