Scalable Alignment of Electron Microscope Image Sections

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Table of Contents

Overview

- **Goals**
  - Scalable alignment of 3D Electron Microscope sections of mouse brain.
  - Integration with CAJAL-3D API for easy image retrieval and upload from database.
- **Difficulties**
  - Approach must be scalable.
  - $1024 \times 1024 \times 2000$ in the smallest data set $\approx 2B$ voxels.
  - Most datasets occupy TB of space; infeasible to align all at once.
- **General Method**
  1. Compute transformations for alignment between adjacent pairs of images using cross-correlation.
  2. Globally align entire image cube using pairwise transformation parameters.

Pairwise Alignment

Objective: Compute transformations to align adjacent pairs of images.

1. Compute pairwise transformation parameters.
2. Improve rotation parameter through error minimization.
3. Refine transformations using image data outside pairwise images to minimize error.

Pairwise Alignment

Compute Pairwise Transformation Parameters

Objective: Determine transformations to align image pair.

For each pair of images:

1. Apply median filtering, histogram equalization, and hamming window.
2. Take Discrete Fourier Transform, apply high-pass filter, and resample in log-polar coordinates.
3. Find best ρ, θ by correlation and max picking.
4. Rotate image, then correlate to find best translation parameters.
5. Use Support Vector Machine (SVM) to identify peak in cross-correlation of image pair.
6. Save transformation parameters.

Pairwise Alignment

Peak Identification

Objective: Determine peaks in cross-correlation of two adjacent images that correspond to translations for correct alignment.

- Support Vector Machine (SVM)
  1. Train SVM classifier with peak features from aligned images (ground truth).
  2. Partition cross-correlation of images into 9 equal parts.
  3. Find point of maximum intensity in each partition.
  4. Sort coordinates from greatest to least maximum intensity.
  5. Classify each potential peak until a peak is found.
  6. If no potential peaks are classified as peaks, then no peaks detected.
- Other Attempted Methods:
  - Choose maximum values.
  - Correlate pairwise cross-correlation with normal distribution.

Pairwise Alignment

Improve Rotation Parameter

Objective: Evaluate correct alignment rotation with finer level of discretization.

1. Given initial estimate of rotation angle θ to align images...
2. For each k, iterate over small window $\theta_{new} = [\theta - k\epsilon, \theta + k\epsilon]$ in increments of ϵ.
3. Compute alignment error with θ_{new} as rotation angle.
4. Update rotation parameter with angle minimizing Mean Squared Error (MSE) for image pair.

Pairwise Alignment

Refine Transformation Parameters

Objective: To align image pair I_2, I_3, use data from images I_1 and I_4.

1. Calculate pairwise transformation parameters between I_1, I_3 and I_2, I_4.
2. Obtain 2 more estimations of transformation parameters between I_2, I_3 using new information.
3. Determine Mean Squared Error between image pair using all estimates of transformations.
4. Pick transformation minimizing error.

Global Stack Alignment

Objective: Given transformation parameters for all adjacent image pairs, compute transformation for each image in global coordinate frame.

1. Set global transformation parameters of previous image to that of current image.
2. Find new rotation angle by adding previous rotation parameter to pairwise rotation angle.
3. Find new translation parameters using previous rotation angle and pairwise translations.
4. Positive translations: shift current image. Negative translations: shift all previous images.
5. Iterate through image cube to globally align stack.

Other Attempted Methods

- RANSAC: detect linear folds
- SURF feature matching: align images
- Superpixels and Earth Mover's Distance: 'better' error metric for image alignment

RANSAC for Fold Detection

- **Objective:** Given set of points P and inlier distance d, outputs line of 'best' fit.
- From P, chooses points and finds line through them.
- Finds number of inliers within d.
- Based on percentage of outliers, adaptively computes number of iterations.
- Use to split image above and below single, linear fold line.

RANSAC for Fold Detection

Results

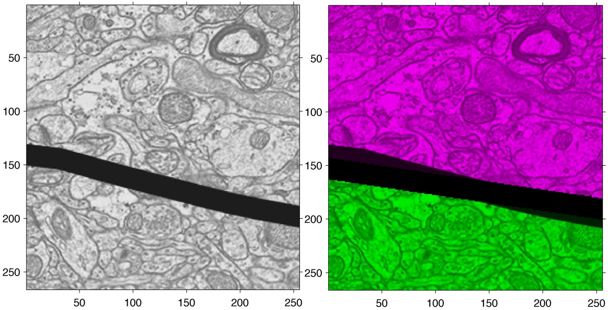

Figure : Fold detection with RANSAC

SURF Feature Detection

- **Objective:** Match image features to correct rotations before cross-correlation step.
- Use Gaussian blur on images, then resize.
- Detect SURF (Speeded Up Robust Features) features.
- Match features to detect rotation angle.
- Rotate image, input for 2D cross-correlation.
- Determine and save transformation parameters.

Superpixels and Earth Mover's Distance

- **Objective:** Weigh alignment error at different regions of the image differently.
- Mean Squared Error weighs every part of the image equally.
- Proposed method between two images:
  - SLIC Superpixels to construct superpixels in both images
  - Each super pixel center is associated with weight related to number of pixels and intensity of pixels
  - Find the Earth Mover's Distance between the cluster centers in image pair.

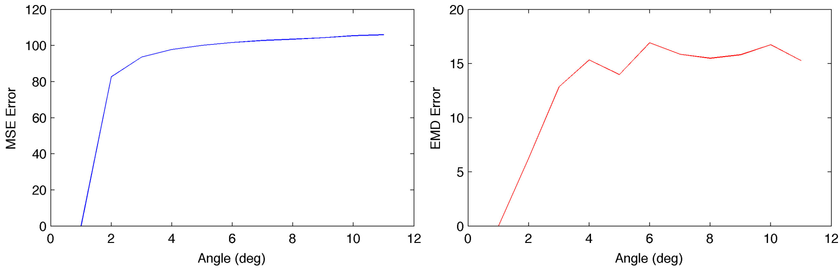

Figure : MSE vs EMD Comparison

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