2D-3D Non-Rigid Registration Using Thin-Plate Spline and Volume Rendering

Jean Y. Song and Charles R. Meyer
Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI

Objectives
We propose a multi-modal 2D-3D non-rigid registration technique to align a single 2D projection image from endoscopy with 3D volumes from CT, MRI or microscopy. The proposed registration technique can further be used to register histology slides or fluorescence microscopy images of adenomatous tissue with colonoscopy images for validation purpose of peptide biomarkers for colonoscopy screening.

Materials & Methods 1
Intrinsic Camera Calibration
The raw video stream from the colonoscopy camera is rectified using geometric camera calibration parameters. Obtain intrinsic calibration parameters in (1) by minimizing re-projection error.

\[ w = \min \{ f_u, f_v, u_0, v_0 \} \]

where \( u \) and \( v \) are image plane coordinates and \( u_0, v_0 \) are real world coordinates. \( f_u \) and \( f_v \) are focal length, and \( (u_0, v_0) \) are principle point. The calibration result is shown in Figure 3.

Data and Coordinate System Definition
3D data set \( A \) to be registered is defined in a coordinate system \( V \). 2D reference data set \( B \) is defined in some coordinate system \( S \).

1) Rigid transform: \( \Phi_1: R^3 \rightarrow R^3 \)
2) Non-rigid transform: \( \Phi_2: R^3 \rightarrow R^3 \) aligns \( A(x_0) \) with \( B(y_0, z_0) \), \( p(x_0) \) and \( q(y_0, z_0) \) are data points from \( A \) and \( B \).

\[ \Phi = \phi(x_0, y_0, z_0) = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \]

The Goal of Registration
where \( \Phi \) is the similarity metric.

\[ \phi = \text{argmax} \left( \Phi(B(x_0)), P(\Phi(A(x_0))) \right) \]

\[ \Phi = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \]

where \( \phi \) is the similarity metric.

\[ \Phi = \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \]

Materials & Methods 2
Landmark based TPS Transformation \( \phi \)
Rigid mappings: two control points selected from \( A \).

Non-rigid mappings: at least one more control point.

\[ p = p + \alpha(s) \]

Figure 3: Example of control points selection.

Future Research
2D-3D image registration is inherently ill-posed unless multiple 2D images are provided. As future research we plan to incorporate a priori knowledge about the surface of colon polyp into the objective function formulation. For example, we can assume that the area of surface does not change too much in vivo and ex vivo. With this assumption we can penalize large changes of the surface area with a regularization term. We also plan to incorporate regularization term encoding direction of control points movement so that control points do not move parallel to the ray direction. Control points movement in ray direction will not affect output projection image and only increase computational time.

We can think of the registration optimization process as minimizing the function \( \Omega \) with respect to the displacements \( \Phi \).

\[ \phi = \text{argmin} \Omega \]

Figure 8 shows 2D example of displacement field without and with area preserving regularization term. Displacement field with area preserving term leads to a more realistic deformation.

We expect that the constraints will reduce the ill-posedness of 2D-3D single projection image to volume registration problem.

Figure 10 shows registration result and the RMS error according to different similarity metrics. Conventional MI, and adaptive Parzen windowed MI seems more accurate, the RMS error of control points are higher than using conventional MI. This is because the control points in the back of the projected scene changes their location regardless of the projected scene. Therefore, we propose to use regularizers to constraint control points movement in our future work.

Conclusions
In this paper, we proposed a new 2D-3D non-rigid image registration technique to map single 2D in vivo colonoscopy images with projection images of 3D ex vivo MRI volumes. Ray casting method for volume rendering on 3D MRI data set was combined with TPS and mutual information to optimize similarity between two images. Experimental result showed that our proposed method registers projection images with high accuracy. However, the ill-posedness of 2D-3D registration problem.

Contact Information
Email jyswkwon@umich.edu
Phone +1 (734) 546 4620

References