# **2D-3D** NON-RIGID REGISTRATION USING THIN-PLATE SPLINE AND VOLUME RENDERING

# **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 cancer screening.



Figure 1: Colonoscopy image (left) and MRI volume (right).

# **O**VERVIEW

Thin-plate spline (TPS) based non-rigid transformation is followed after a 6 degree of freedom (DOF) rigid transformation for coarse alignment of an ex vivo 3D MR data set with in vivo 2D colonoscopy images. To acquire projection images from 3D MR data, ray casting through the data set is performed after transformation. The opacity of a sample is determined by a nonlinear mapping to the intensity value of the sample. The perspective parameter of a ray is obtained by computing the focal length of the colonoscopy camera using geometric camera calibration. For similarity measure, adaptive Parzen windowed mutual information (MI) is used because of its robustness in multi-modal registration. We adopt Nelder-Mead simplex method for optimization.



Figure 2: Block diagram of the proposed non-rigid registration scheme.

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**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.

where *u* and *v* are image plane coordinates and  $x_e$ ,  $y_e$ , and  $z_e$  are real world coordinates.  $f_x$  and  $f_y$  are focal length, and  $(u_0, v_0)$  are principle point. The calibration result is shown in Figure 3.



Figure 6: 25 raw images of planar checkerboard was taken from the colonoscope to be used for calculating calibration parameters.

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 xform:  $\Phi_R : \mathbb{R}^3 \to \mathbb{R}^3$  defines the relation of V with S. 2) Non-rigid xform:  $\Phi_{NR} : \mathbb{R}^3 \to \mathbb{R}^3$  aligns  $A(x^{3D})$  with  $B(y^{2D})$ .  $x^{3D}$  and  $y^{2D}$ : points of data A and B.  $\mathcal{P}$ : a projection matrix.

 $\Phi = ar$ 

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 area of surface of colon polyp into the objective function formation. 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 minimization of the function  $\Omega$  with respect to the displacements  $\Phi$ :

where  $\Omega$  corporates two regularization terms:

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# MATERIALS & METHODS 1

$$v \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & u_0 \\ 0 & f_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix}.$$
(3)



Figure 7: Geometrical setup of the registration

**The Goal of Registration** where  $\mathfrak{S}$  is the similarity metric.

$$\operatorname{rgmax}_{\Phi}\left(\mathfrak{S}(B(y^{2D}), \mathcal{P}\{\Phi\{A(x^{3D})\}\})\right), \{\Phi_R, \Phi_{NR}\} \in \Phi.$$
(4)

# 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.

Volume Ray Casting A ray for each desired pixel in image domain  $\Omega_{B_i}$  is generated. Samples are taken along each ray by tri-linear interpolation of the surrounding voxels.

*p*: intensity of a pixel.  $s^{(m)}$ : interpolated intensity.  $\alpha^{(m)}$ : opacity. *S*: sum of opacity of samples.  $\hat{p}$ : final output pixel value.

$$p =$$

The opacity of *m*-th sample,  $\alpha^{(m)}$ , is determined by a nonlinear mapping to the intensity value of the sample.



Note that the distance *d* correspond to the focal length of the colonoscopy camera computed by intrinsic camera calibration.

# FUTURE RESEARCH

$$\tilde{\Phi} = \operatorname{argmin}_{-} \Omega$$

$$\Omega = D(\Phi) + \alpha R_A(\Phi) + \beta R_D(\Phi)$$

where  $D(\Phi) = \mathfrak{S}(B(y^{2D}), \mathcal{P}\{\Phi\{A(x^{3D})\}\}), \{\Phi_R, \Phi_{NR}\} \in \Phi \text{ and } \mathfrak{S}$ is the similarity metric.  $R_A(\Phi)$  is for area preservation of surface, and  $R_D(\Phi)$  is for the direction of control points movement.

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.



straint, respectively.

(5)

(6)



Figure 3: Example of control points selection.



Figure 4: Simplification of a ray.

 $p + \alpha^{(m)} s^{(m)}, \quad S = S + \alpha^{(m)}$ 

**Figure 5:** The ray intersecting *s* can be expressed as r(t) = e + td.

$$\boldsymbol{s} = \boldsymbol{e} + u\boldsymbol{u} + v\boldsymbol{v} - d\boldsymbol{w}$$

Figure 8: Displacement field without and with area preservation con-

# RESULTS

Volume Ray Casting A white light projection image from colonoscopy video and volume rendered MR image.



Figure 9: Two projection images to be registered.

Preliminary Result of 2D-3D Registration T1-weighted  $256 \times 256 \times 70$  MR volume of ex vivo mouse colon section was used for simulation. A random 2D ray traced projection image of the MR volume was taken for functioning as a synthesized colonoscopy image. The same 3D MR volume was set as the homologous volume. Six control points were manually chosen uniformly throughout the volume to perform 3D non-rigid TPS geometric transformation. After transformation, a ray casting projection 2D image was generated from the MR volume. The 2D joint histogram and MI between the phantom reference image and 2D projection image was computed. If MI were not maximum, the control points were moved according to the optimizer. Transformation and MI computation process iterated till the MI maximizes.



Figure 10: First row: conventional MI (RMS error 0.6899). Second row: adaptive Parzen windowed MI (RMS error 1.1204).

Figure 10 shows registration result and the RMS error according to different similarity metrics. Conventional MI, and adaptive Parzen windowed MI. Even though the registration result of 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.

# CONCLUSION

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



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