MR-guided prostate interventions with 3D Slicer and the NA-MIC Kit

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This tutorial will teach you how to perform the steps required for MR-guided prostate interventions using Slicer3.

In particular, you will learn how to:

- Register pre-operative and intra-operative prostate MR images using deformable B-spline registration
- Incorporate models of the neurovascular bundle using image segmentation and model making
- Manually segment images
- Create 3D models from segmentations
Prerequisites

This tutorial assumes that you have already completed the tutorial **Data Loading and Visualization**. Tutorials for **Slicer3** are available at the following location:

- **Slicer3 tutorials**
  
This tutorial requires the installation of the Slicer3 software and the tutorial dataset. They are available at the following locations:

- **Slicer3** download page (*Slicer 3.2*)
- Tutorial dataset (*MRGuidedProstateInterventions.zip*)

**Disclaimer:** *It is the responsibility of the user of Slicer to comply with both the terms of the license and with the applicable laws, regulations, and rules.*
Overview

1. MR-guided prostate interventions: clinical background

2. Registering pre-operative & intra-operative prostate MR images using deformable B-spline registration

3. Manual segmentation of images

4. Creating 3D models from segmentations
MR-guided prostate interventions: clinical background
Prostate cancer

- Prostate cancer has the second-highest mortality rate of all cancers in American men: one in six men will be diagnosed, and it kills one in thirty-five (American Cancer Society)

- **Diagnosis:**
  - Prostate specific antigen (PSA) level
  - Digital rectal exam
  - **Needle biopsy** (Gleason score)

- **(Some) Treatment options:**
  - “Watchful waiting”
  - **Brachytherapy**
  - External beam radiation therapy
  - Radical prostatectomy
Guidance for biopsy/brachytherapy

- **Image guidance:**
  - allows specific locations within the prostate to be targeted
  - provides updates of the needle’s current position and orientation

- Models can be used to highlight the prostate, the tumour, and structures to be avoided (such as the neurovascular bundle)
MR-guided prostate interventions

**pre-operative**
- pre-operative MR imaging (high quality)
- (optional) segmentation model making

**registration**
- compensates for change in patient position
- presence/absence of endorectal coil

**intra-operative**
- intra-operative MR imaging (lower quality)

Guidance based on intra-operative image fused with higher quality pre-operative image and models of important structures
The Prostate MR Image Database

http://prostatemrimagedatabase.com

- Provides prostate MR images for a variety of clinical situations, including prostate cancer biopsy and brachytherapy
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Registering pre-operative & intra-operative prostate MR images
**Image Registration**

- Image registration aligns two images together with the goal of making the corresponding anatomy overlap

**Pre-operative**
- T2 FSE at 1.5 T, endorectal coil
- Pixel spacing: 0.46875mm x 0.46875mm
- Slice thickness: 3mm

**Intra-operative**
- T2 FSE at 0.5 T, body coil
- Pixel spacing: 0.9375mm x 0.9375mm
- Slice thickness: 5mm
Three transformation models

Rigid

• Translation
• Rotation

Affine

• Translation
• Rotation
• Stretch
• Shear

Non-rigid

• Non-linear, e.g. spline-based, elastic/fluid models
Deformable B-spline registration

- Similarity measure: mutual information
- Optimizer: itkLBFGSB (limited memory Broyden Fletcher Goldfarb Shannon minimization with simple bounds)

B-splines in Slicer3:

- B-spline grid
- Control points
- Pixel displacements
Registration Steps

- Load the image volumes
- Initial manual rigid transformation
- Automatic affine registration
- Automatic deformable B-spline registration
Registration Steps

- Load the image volumes
- Initial manual rigid transformation
- Automatic affine registration
- Automatic deformable B-spline registration
Load the pre-operative image

Open the Volumes Module
Load the image volumes

Click on “Select Volume File”
Load the image volumes

Select the pre-operative image: preoperative.nrrd

Click “Open”
Click “Apply”

Expand the Display tab

Turn thresholding off

Adjust the Window/Level sliders until you can see the image

Load the image volumes
Load the image volumes

Click on the slice control link button

Toggle the slice visibility to see the slices in the 3D viewer

Center the 3D view on the scene and zoom in
Load the image volumes

Use the slice selector sliders to explore the dataset
Load the intra-operative image

Click on “Select Volume File”
Select the intra-operative image: intraoperative.nrrd

Click “Open”
Load the image volumes

Click “Apply”

Turn thresholding off

Adjust the Window/Level sliders until you can see the image

Center the 3D view on the scene
Load the image volumes

Note that the images are not aligned

Set the foreground to the pre-operative image

Scale between the foreground and background
Registration Steps

- Load the image volumes
- Initial manual rigid transformation
- Automatic affine registration
- Automatic deformable B-spline registration
Manual rigid transformation

Open the Transforms module
Manual rigid transformation

Create a new linear transform
Manual rigid transformation

Open the Data module
Apply the manual rigid transformation to the pre-operative image

Drag the pre-operative image under the Linear Transform1 node
Manual rigid transformation

Open the Transforms module
Manually adjust the translation and rotation parameters to align the two image volumes.

**Recommended:**
- Trans. LR: -12
- Trans. PA: -6
- Trans. IS: 97
- No rotation
Manual rigid transformation

Scale between the foreground and background to evaluate the alignment
The initial transformation "pushes" the pre-operative image onto the intra-operative image, but Slicer’s registration algorithm expects the inverse
Manually rigid transformation

Click on the “Invert” button

Scale between the foreground and background - note that the two images are no longer aligned
Registration Steps

- Load the image volumes
- Initial manual rigid transformation
- Automatic affine registration
- Automatic deformable B-spline registration

Initializes transform

Initializes transform
Perform the affine registration

Open the Affine Registration module
Create a new affine registration transform

You do not need to change any of the registration parameters
Affine registration

Initial transform: Linear Transform1

Output transform: Create new linear transform
Affine registration

Fixed image: intra-operative
Moving image: pre-operative
Output Volume: None
Click “Apply”

View the progress bar and wait until it says “Completed”
Affine registration

Evaluate the affine registration

Open the Data module
Drag the pre-operative image under the Affine registration Transform1 node.
Affine registration

In order to evaluate the affine registration, the transform must be inverted back.

Open the Transforms module.
Affine registration

Change the transform node to the affine registration transform

Note that the affine transform is different from the rigid transform that we manually specified.
Affine registration

Click on the “Invert” button

Scale between the foreground and background to evaluate the alignment
Now that we’ve evaluated the affine transform, it must be inverted before it can be used to initialize the deformable B-spline registration.
Click on the “Invert” button

We are back to the original transform given by the affine registration: note that once again, the images are not aligned.
Registration Steps

• Load the image volumes
• Initial manual rigid transformation
• Automatic affine registration
• Automatic deformable B-spline registration
Deformable B-spline registration

Perform the deformable B-spline registration

Open the Deformable Bspline Registration module
Create a new deformable B-spline registration transform

You do not need to change any of the registration parameters
Deformable B-spline registration

Initial transform: Affine Registration Transform1
Output transform: None
Deformable B-spline registration

Fixed image: intra-operative
Moving image: pre-operative
Output Volume: Create new volume
**Deformable B-spline registration**

Click “Apply”

View the progress bar and wait until it says “Completed”

Set the foreground to the intra-operative image
Deformable B-spline registration

Evaluate the deformable B-spline registration

Scale between the foreground and background to evaluate the alignment
Compare the deformable B-spline registration results to the affine results.

The affine transform must be inverted back.

Open the Transforms module.
Deformable B-spline registration

Click on the “Invert” button

Set the foreground to the pre-operative image

Scale between the foreground and background to evaluate the alignment

Note non-linear warp!
Final results:

Set the foreground back to the intra-operative image.
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Manual Segmentation

Manual segmentation is the process of delineating the anatomical structures within an image.
Prostate MR dataset

T2-weighted axial image at 3.0 Tesla

Central gland, peripheral zone, neurovascular bundles and rectum shown
**Prostate MR dataset**

T1-weighted axial image at 3.0 Tesla

The T1 image can be used to complement T2 imaging visualization.
Load the data

Sample segmentation data were previously saved in a scene file.

Select “Load Scene” from the File menu.
Select T2.mrml from the file selection menu and click “Open”

This scene contains T2 and T1 MR, plus an example label map
Select layout

Select the "Red slice only layout"

This will display axial MR slices for the segmentation
Manual Segmentation – Visibility

**Toggle visibility**

Toggle visibility to foreground so that the T2-weighted image appears.

The toggle allows for easy visualization of both the T1 and T2 images.
Manual Segmentation – Visibility

Fit visible

The fit visible button zooms the image to fit the window.

This presents the maximum image size to aid in visualization.
Manual Segmentation – Editor

Open the Editor module

The Editor module contains Slicer’s drawing tools
Manual Segmentation – Source

Select the source volume

This is the volume you will be drawing on

Select the T2 volume for this demonstration
Enter a label map name
The label map will contain the segmentation results

Enter “Label” as the label map name

Press “Create Label Map”
Manual Segmentation - Draw

Select the draw tool

Click on the pencil icon

The draw tool is used to contour regions of interest
**Manual Segmentation - Color**

**Select color**

Click on the color box for the pop-up color selector

Use a different color for each anatomical region
**Manual Segmentation - Contour**

**Draw a closed contour**

Contour the prostate

Press the ‘a’ key to fill in the region when complete
Manual Segmentation - Contour

The contour is filled in when ‘a’ is pressed.

Here the boundary of the prostate gland has been contoured.
Manual Segmentation - Color

Select color

Change to a different color for another structure

Click on the color box for the pop-up color selector
**Manual Segmentation - Contour**

**Draw a closed contour**

Contour the right neurovascular bundle

Press the ‘a’ key to fill in the region when complete
Manuel Segmentation - Contour

The contour is filled in when ‘a’ is pressed.

Here the right neurovascular bundle has been contoured.
Set label opacity

This allows you to see beneath the contoured regions

Select a value for the opacity using the pop-up slider
Now you can visualize the MR image and the selected regions at the same time
Manual Segmentation - Color

Select color

Change to a different color for another structure

Click on the color box for the pop-up color selector
Manual Segmentation - Contour

Draw a closed contour

Contour the tumour

Press the ‘a’ key to fill in the region when complete
Here a suspected tumor has been contoured.

The contour is filled in when ‘a’ is pressed.
To erase, draw with black

Click on the color box for pop-up color selector and choose black (label zero)
Contour the region to be erased
Press the ‘a’ key to erase the region when complete
Segment all slices in the volume

For each slice in the volume segment the prostate, both neurovascular bundles and the tumour: use a consistent color scheme.
Manual Segmentation - Save

Save the segmentation

Select “Save” from the File menu

Save the labels and current settings in a scene file
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Creating Models

We can create 3D models of the anatomy to enhance our visualization.
Creating Models - Select Module

We will load the “Model Maker” module.

The Model Maker module makes 3D triangulated surfaces from segmentations.
Creating Models - Select Module

Open the Model Maker module

(Other model choices may apply for other applications)
Creating Models - Input Volume

Choose the input volume

This is the volume called “Label” in this demonstration

Each label value in the label map can be made into a surface model
Creating Models - Hierarchy

Create a new model hierarchy

Hierarchies can be used to organize 3D models into groups
Creating Models - Hierarchy

Select “Create New Model Hierarchy”
Creating Models - Generate

**Generate models**

Check the box “Generate All Models” box

(You could also generate models individually for each label value)
Press the “Apply” button

Slicer will create all the models
View the models in 3D

We can visualize both the models and the image slices in 3D
Creating Models - View

Select “Conventional Layout”

This view allows for viewing both image slices and 3D space
Creating Models - View

The 3D view appears

Surface structures appear colored by their label colors
Creating Models - View

The mouse can be used to rotate the surfaces.

The letters S/I A/P and R/L help with spatial orientation.
Creating Models - View

View the cross-sectional slices by pressing the “eye” button above the slice(s)
Creating Models - Save

Save the models

The models need to be saved or they will be lost

Select “Save” from the “File” menu
Make sure “Save” is checked next to the models and “Save Scene”
Conclusions

- The NA-MIC Kit can be used to perform the major computational steps in MR-guided prostate interventions

- Slicer3 provides an intuitive graphical user interface to interact with the data

- The NA-MIC Kit’s open-source environment allows clinicians and researchers to share data and solutions to common problems
For more information

• For an example of using intraoperative MR for prostate interventions, see:
  

• For a review of non-rigid image registration, see:
  
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