3D Image Coregistration

1. Introduction

This Quick Start guide describes FireVoxel's tools for image registration in the main menu's **Register** group, illustrated by different scenarios:

1) **Coregister using Orientation\Position tags** – MRI to MRI acquired in the same subject in the same imaging session;
2) **Coregister using Mutual Information with AutoFocus** – CT to MRI;
3) **Landmark registration** – ultrasound to MRI.

Users will need to select the tools that are best suited for their images, required registration accuracy, computational resources, and processing time.

During registration, one image (**source**) is transformed and aligned with another image (**target**) that remains unchanged. The resulting **coregistered** image has the same resolution as the target image. This naming convention will be followed throughout this document.

2. Coregister with DICOM tags

FireVoxel's basic coregistration command – **Register** > **Coregister Using Orientation\Position tags** – uses the orientation and positon information extracted from the DICOM headers. This method works best for images acquired *during the same imaging session*. The patient position is assumed to be unchanged between the two acquisitions. The source and target images may have different resolution and imaging orientation. In addition to DICOM, this command may work for NIfTI images that unambiguously store the image orientation information. This method is fast and requires no parameters to be adjusted.

Steps:

1) Open the source image in FireVoxel. If the images are stored in DICOM format, use **File** > **Open DICOM folder: Single document**. The DICOM Tree dialog will be displayed (Fig. 1). Select the needed series and click **Load**. The source image will be displayed in a new document window.
2) Alternatively, if the images were previously saved as a FireVoxel document, use **File** > **Open FireVoxel document**. If images are stored in NIfTI format (*.nii, *.nia) or another image format, load images using **File** > **Open Image**.
3) Open **Layer Control** by double-clicking on the image. If the source document contains multiple layers, including ROIs, make sure that the base layer (acquired image, MRI, CT, PET, etc.) is the active layer (indicated by the red outline around the layer name). Keep **Layer Control** open.

4) Now open the target image in another document window (Fig. 2). Make sure that the target window is the active window by clicking on it. The **Layer Control** will display the layers in the active window. The active window is indicated by the blue title bar at the top of the window. Also make sure that the base image is the active layer.

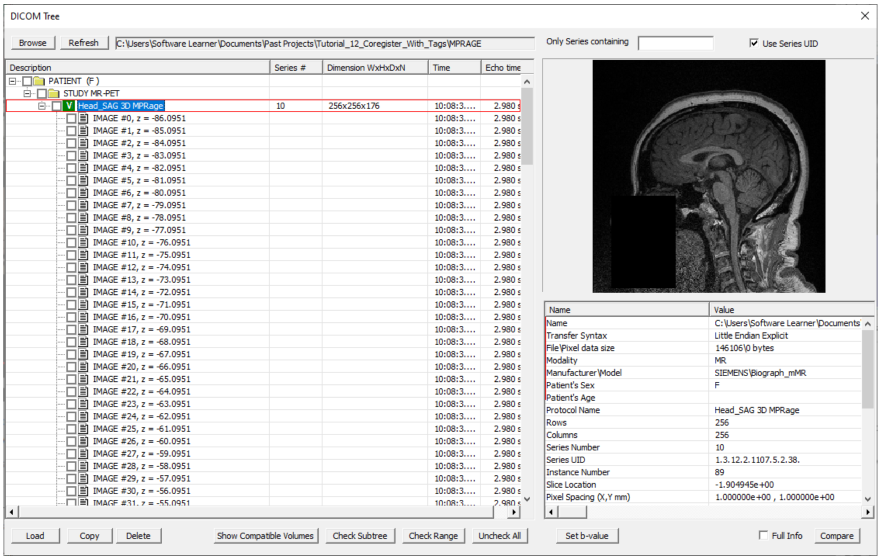


Fig. 1. Images loaded using File > Open DICOM folder: Single document. The command opens DICOM Tree dialog displaying images in the selected folder (T1-weighted MPRAGE).

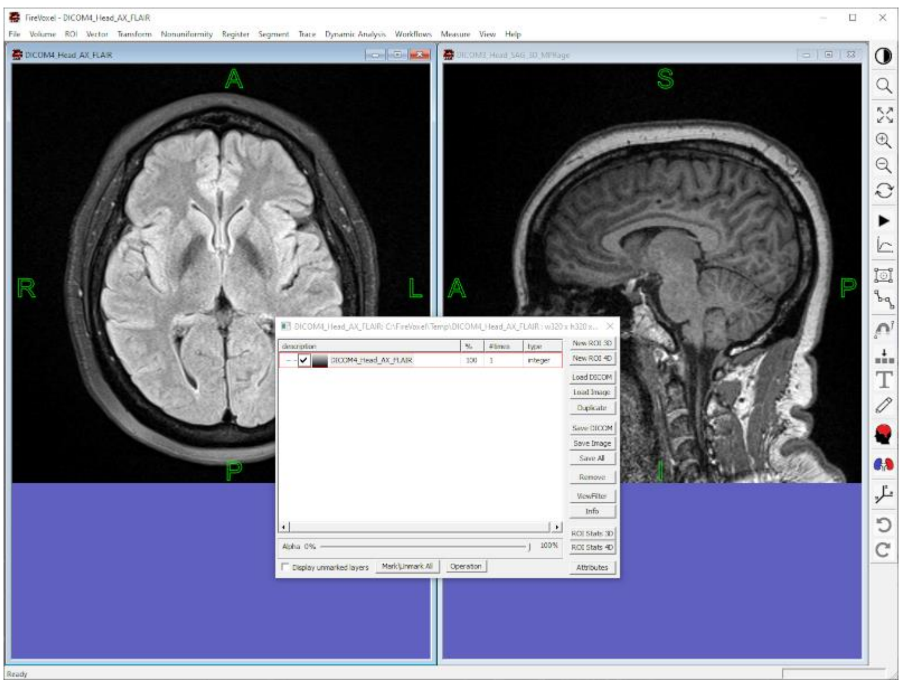


Fig. 2. Images for coregistration using DICOM tags. Left: Target image (T2-weighted, active window). Right: Source image (T1-weighted (active layer) and segmentation mask (ROI layer)). The Layer Control panel shows the layer content in the active window (left, target).

5) Select **Register** > **Using Orientation\Position tags** on the main menu.

6) A dialog opens with the output options (Fig. 3). Select an option to start processing or cancel:
    a. *Add as a new layer* – Coregistered image will be added to the target window as a new (topmost) layer;
    b. *Create new Document* – Coregistered image will be displayed in a new document window;
    c. *Cancel* – Cancel the operation.

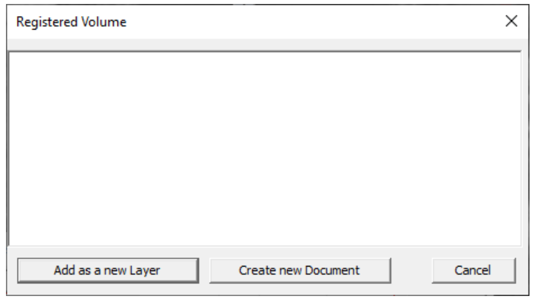


Fig. 3. Coregister with DICOM tags > Output options dialog.

7) When the registration is completed, the coregistered image will be displayed according to the selected option: (a) in a new layer or (b) in a new document window. The new layer or document is labeled [source]_reg (Fig. 4). All layers of the source image will be coregistered together and placed either into the target window or into the new document window.

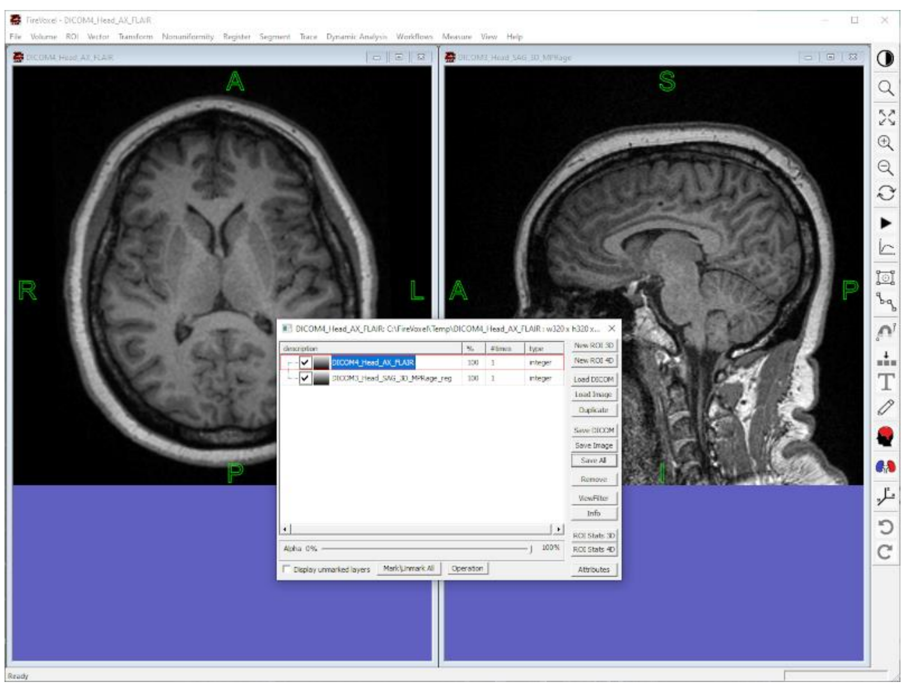


Fig. 4. Coregistration with DICOM tags: Results for coregistered image added as a layer in the target window. Left: Target window with 3 layers – target (T2-weighted image) and two coregistered layers (T1-weighted image and ROI).

8) Check the accuracy of registration. Open **Layer Control**, use the **Alpha** slider to adjust the layer transparency to inspect the coregistered image. Displaying one of the layers as a color map

instead of grayscale (**Layer Control** > **View Filter** > select color map) may also be helpful for verifying the accuracy of alignment.

9) If coregistration accuracy is unacceptable, try a more advanced coregistration method, such as **Register** > **Mutual Information with AutoFocus**.

3. Coregister Using Mutual Information with AutoFocus

Coregistration with **Register** > **Mutual Information with AutoFocus** works for images acquired during different imaging sessions or even with different modalities. This method may use a target ROI enclosing the organ or tissue of interest to restrict coregistration and speed up processing. Coregistration can be performed without the target ROI, but it may take much longer than with the ROI.

Steps:

1) Open the source image in one document window.
2) Open the target image in another document window.
3) Define a rough *target ROI* enclosing the organ or tissue of interest. You may use manual or automatic segmentation tools (Fig. 5).
    a. For a manual ROI, use **Layer Control** > **New ROI 3D** to create a new ROI layer.
    Use the paintbrush tool (Ctrl+Left mouse) to draw a rough contour around the organ of interest. Define these contours on every few slices (e.g., on every 5th slice). Next, use **ROI** > **Morphology** > **Fill 2D Contours and Morph Convex** to fill the contours and extend the ROI across slices. The resulting ROI should fully enclose the organ or tissue of interest.

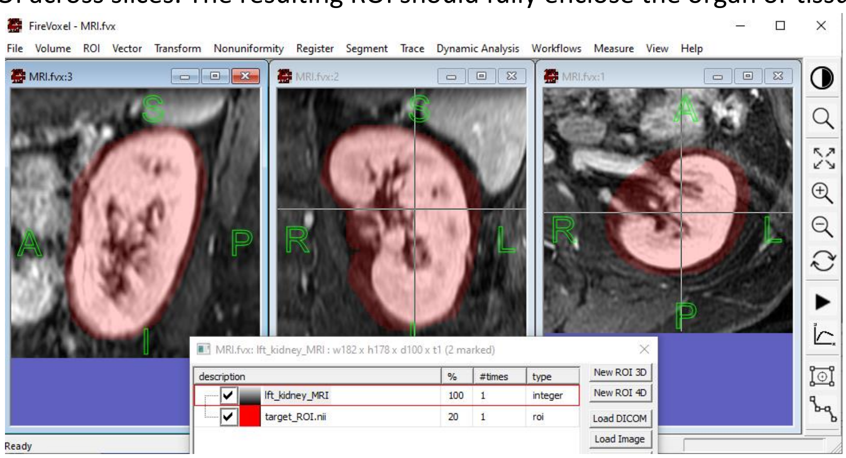


Fig. 5. Target image with a rough target ROI enclosing the kidney (organ of interest), displayed in three orthogonal projections.

4) Select the target window as the active window and select the base image as the active layer (Fig. 6). Select **Register** > **Mutual Information with AutoFocus**.
5) If the active layer is an ROI layer, a warning will be shown: **Target vs ROI. Proceed?** The user is advised to click **No**, select the base image as the active layer, and repeat registration command.
6) If the active layer is the base image, a dialog window will open (3D Registration with AutoFocus, Fig. 7).

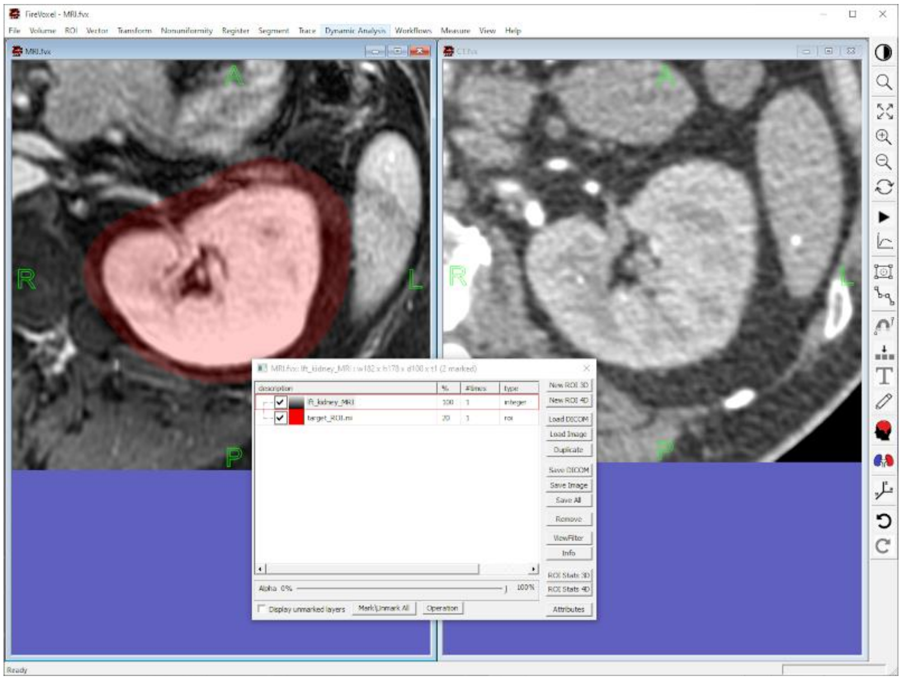


Fig. 6. Left: Target window with the base image of the left kidney (MRI) and target ROI. Right: Source image (CT) of the same kidney.

7) Check the **Use Target ROI** box (it is checked by default if an ROI is present).
8) Select suggested AutoFocus and Finetune parameters. It is recommended to start with **AutoFocus: Translation** and **Rotation** only and **Finetune: Transform** > **Rigid**.
9) Click **OK** to start processing. Registration will commence. Its progress will be indicated in the bottom right corner of the software window.

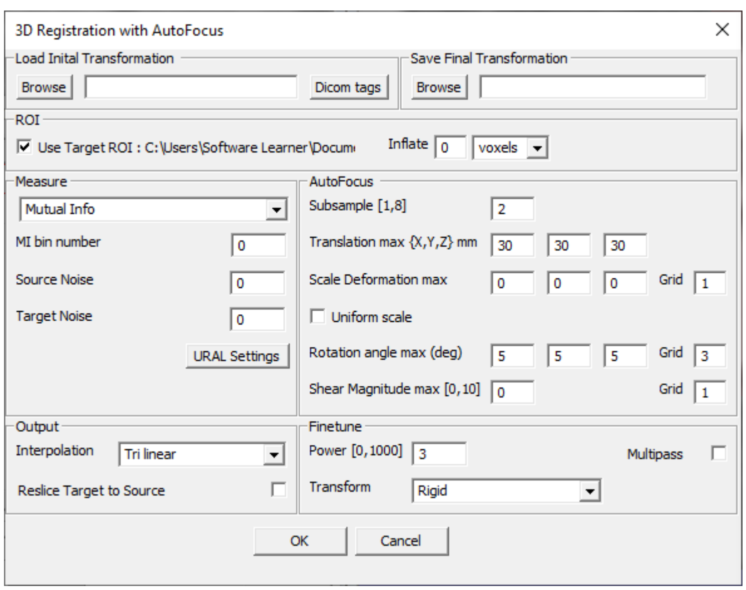


Fig. 7. 3D Registration with AutoFocus dialog with suggested settings.

10) When registration is completed, a new layer with coregistered image will be created in the target window (Fig. 8).
11) Check registration accuracy using **Layer Control** > **Alpha** slider to adjust the transparency of the coregistered layer.
12) If registration accuracy is unacceptable, repeat steps 5-9 and adjust the coregistration parameters one at a time on each iteration.

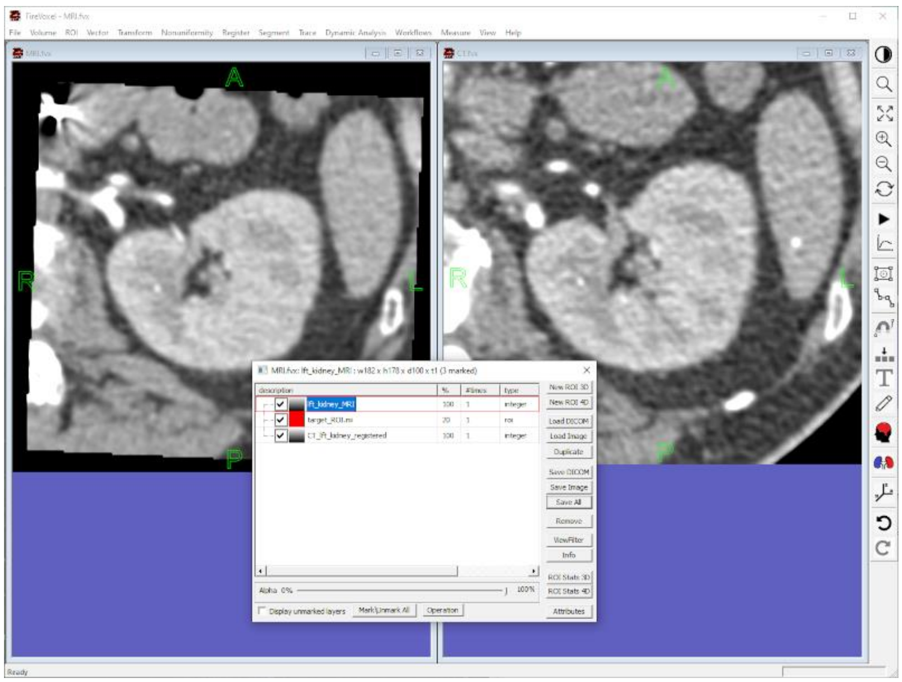


Fig. 8. Results of Register > Mutual Information with AutoFocus operation. Right: Target MR image with coregistered CT image superimposed on top.

4. Details on Coregistration with AutoFocus Dialog

The coregistration algorithm searches for a transformation that best matches the source and the target volumes. The transformations range from simple translations to affine. The matching of the volumes is based on optimizing a **similarity measure**. The user may choose from several similarity measures, from simple and quick to complex and thus more computationally "costly". The similarity measures include: 1) Signal Difference, 2) Cross Correlation, 3) Image Ratio Uniformity, 4) Mutual Info, 5) Mutual Info Normalized, 6) URAL, 7) URALTAU.

The transformation is computed in two stages, AutoFocus and fine-tuning:

1. **AutoFocus.** The algorithm constructs a variety of transformations with combinations of parameters that span a multidimensional grid. The transformations include translation, scaling, rotation, and shear. By default, only translations are considered. The volume is subsampled. The transformations are ranked by how well they match the two volumes based on the similarity measure. A user-selected number of the best transformations is retained for the second, fine-tuning stage (Power field, default: 1).

2. **Fine-tuning.** The algorithm performs iterative adjustment of the best transformation parameters until it finds a local optimum of the similarity measure. Finally, the transformed source image is interpolated and saved as a new layer in the target image window.

The recommended strategy for achieving satisfactory coregistration is to start with the simplest settings, transformations, and similarity measure and progressively add more complex options one at a time to obtain more accurate registration results. The user may try adjusting the following options: 1) increase **Power**, 2) add rotations and other transformations, or 3) upgrade the similarity measure.

5. Landmark Coregistration

Another coregistration method is coregistration with landmarks. This option is the least preferable and should be used as a last resort. It may be used when a fully automatic process may not provide accurate results, for example, to coregister images acquired with different modalities, or acquired images and atlas maps.

Landmark coregistration alignes two images by superimposing their landmark locations, or prominent sites that can be easily identified on both images. The user marks these locations by placing pairs of vector regions of interest (VROIs) at the matching locations of the target and source images. The source image is then transformed to match the coordinates of its landmarks with the landmark coordinates of the target image.

Steps:

1) Open source image in one document window.
2) Open target image in another document window (Fig. 9).

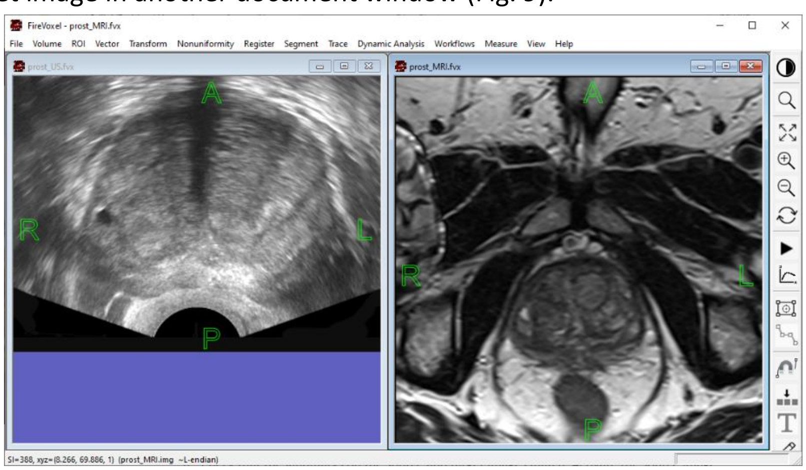
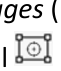


Fig. 9. Source (left, ultrasound) and target (right, MRI) images of the prostate for cross-modality coregistration with landmarks.

3) Place the same number (at least three) of matching vector ROIs (VROIs) over easily identifiable locations (landmarks) on the *source* image and the *target images* (Fig. 11).
    a. Use **Vector** > **Construct Vector ROI** or the toolbar tool  to draw VROIs.

b. Open **Vector ROI Properties** dialog by double-clicking on the VROI (Fig. 10). For each location, enter a unique VROI name into the **name** text field.

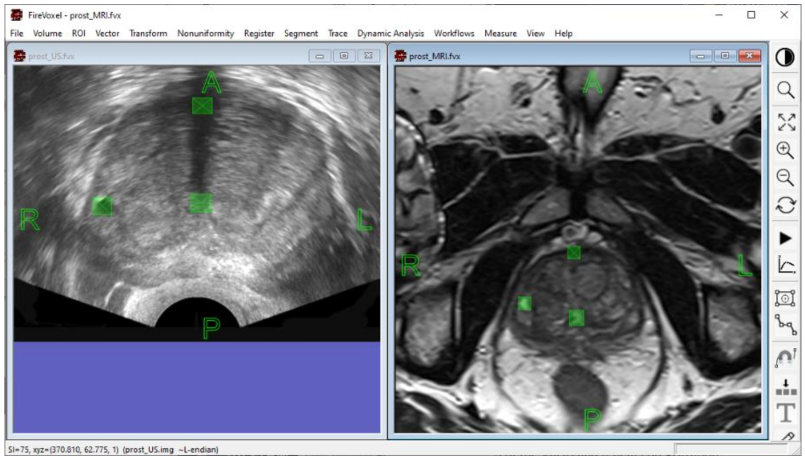


Fig. 11. Source and target images with 3 VROIs (green rectangles) on each image.

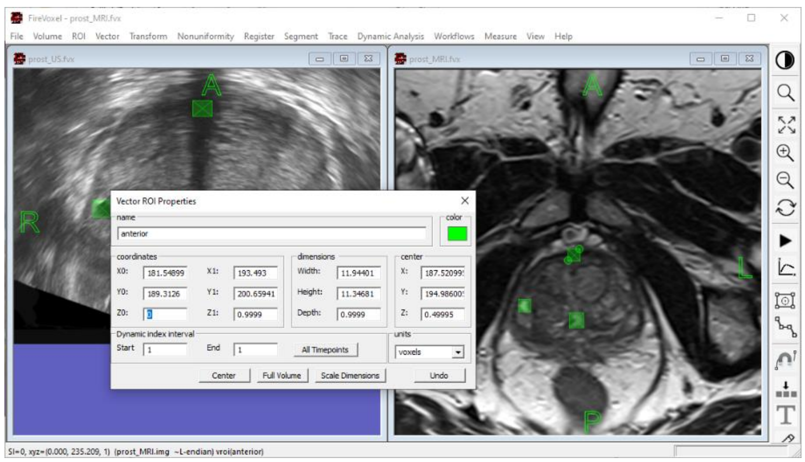


Fig. 10. Vector ROI Properties dialog for the active VROI on MRI (with circles over corners) with VROI name defined as 'anterior'. The matching VROI on the ultrasound image (next to the letter A) has the same name.

4) Check that the landmarks on the source and target images match. Activate the source image, then select **Vector** > **List All Vector ROIs**. A dialog with all VROIs in the source document window will be displayed (Fig. 12). Note the list of VROIs (or take a screenshot). Then activate the target

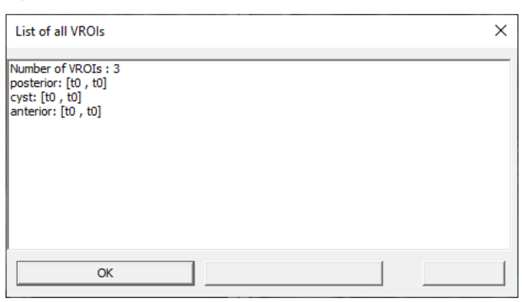


Fig. 12. Vector > List All Vector ROIs displays a list of all VROIs in the document.

window and again display the list of VROIs. The two sets must contain identical sets of VROIs, with matching numbers and names (the order of VROIs does not matter).

5) Activate the *target image*. Select **Register** > **Landmark Registration**. This will open a dialog (**Register Volumes using Landmarks**, Fig. 13) to adjust the parameters. Select the interpolation type best suited for the imaging modality. To save this transformation for the future, click **Browse** next to the **Transformation File** text field. This will open browse-for-file to specify the location and name of the volume transform file (*.vtf).

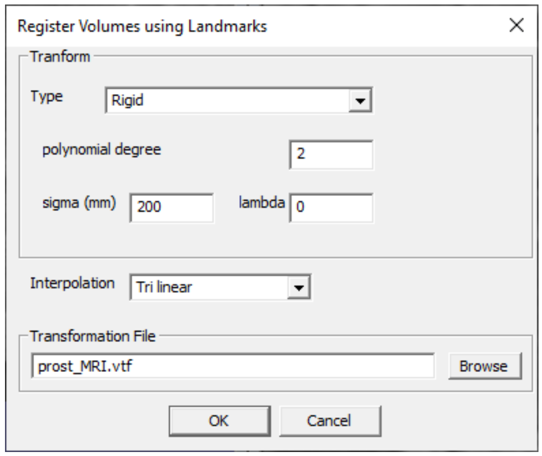


Fig. 13. Register > Landmark Registration opens dialog to adjust the parameters and save the transformation file (optional).

6) If mistakes were found in defining landmarks (e.g., mismatched number of VROIs), an error message will be shown. Check the number and names of the VROIs and repeat coregistration.

7) Click **OK**. If no gross mistakes were found in defining the landmarks, image processing dialog will be displayed (Fig. 14) with the basic measures for each VROI, the transformation matrix, and root mean square error (RMSE). If the distances and errors are acceptable, click Yes to proceed with the coregistration. Large distances and errors may signal that landmarks were mislabeled.

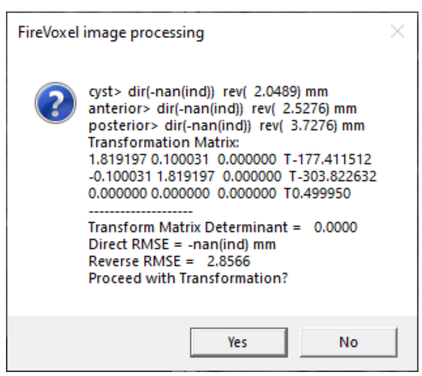


Fig. 14. Image processing dialog shown if no gross errors in landmarking were found. The dialog shows distances between landmarks and the transformation matrix.

In this case click No to cancel the operation, correct the VROI labels and repeat the coregistration operation.

8) If the user clicks Yes, the coregistered image will be created and added as a new layer in the target document window (Fig. 15). If transformation was saved as *.vtf, this file will be created at the specified location.

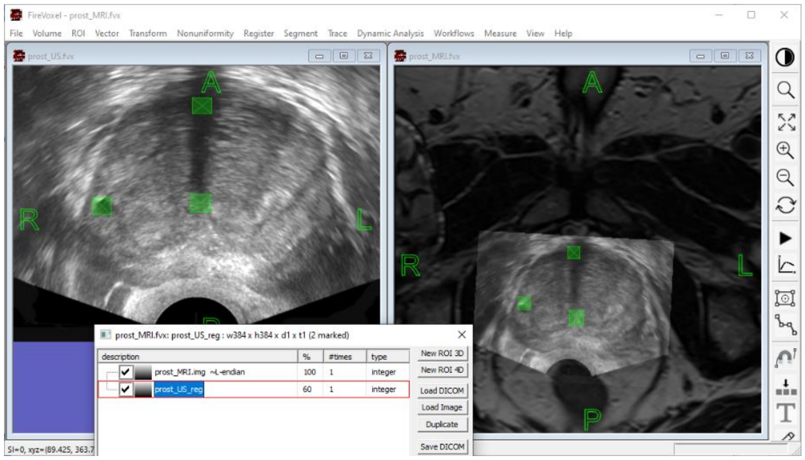


Fig. 15. Result of landmark registration. Target image (right, MRI) has a new layer (named prost_US_reg) with coregistered ultrasound image.

9) Use **Layer Control** > **Alpha** and **ViewFilter** to check the accuracy of coregistration. To improve landmark registration, use more advanced transformation and adjust the parameters on the **Register Volumes using Landmarks** dialog).