PET/MR Image Fusion and Co-registration: ParaVision360 Based Workflow

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Introduction

The combination of Positron Emission Tomography and Magnetic Resonance Imaging (PET/MRI) has enabled us to join the anatomic and analytical strengths of MR imaging with sensitive functional information gained from PET. This has opened the possibility to perform multi-parametric evaluations and accurate quantitative analysis of the structural and functional parameters from PET/MR [1]. An important aspect of realizing the advantages of two imaging modalities with completely different principles of operation but providing complimentary information is image co-registration. To achieve a high standard of accuracy for relevant observations using image co-registration, it is necessary to avoid the ambiguity that arises from manual image registration techniques. In effect ParaVision360 utilizes automated image registration process without any manual intervention.
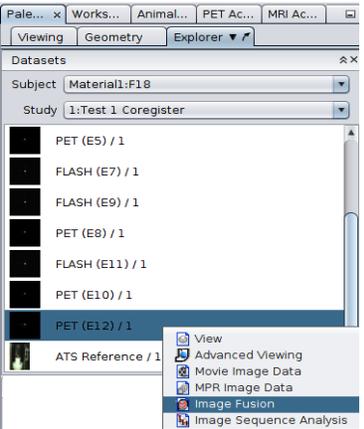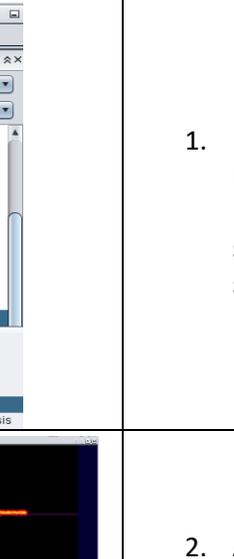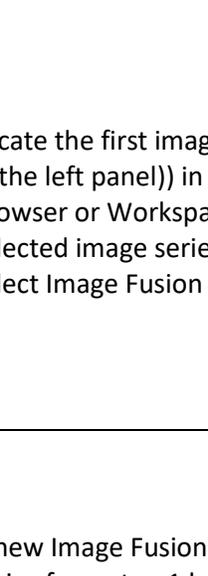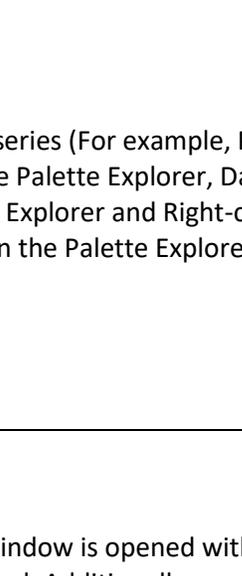
ParaVision360 provides simple workflows for both sequential and simultaneous PET/MRI acquisitions and post-processing. In this application note we will describe two workflows: (1) to compare or visualize the data by overlaying the two datasets (Image Fusion) and when necessary (2) to improve the geometric alignment between the two datasets (Image Registration).
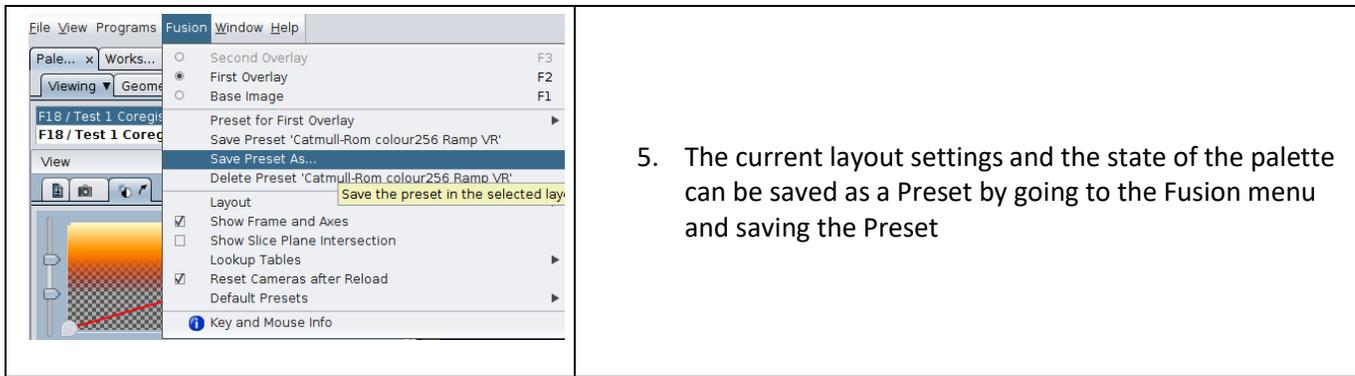
Protocol

Image Fusion

To compare and visualize the datasets from two different modalities, ParaVision360 provides the automatic Image Fusion functionality. This fusion is based on the geometry description of the image datasets and relies on the geometric calibration of the instrument performed during system installation. Table 1 describes the workflow to obtain a fused dataset after image acquisition with the two imaging modalities (PET and MR datasets are used as example in table 1) are completed.

Table 1: ParaVision360 workflow for visualization of the Fused image series

ParaVision360 Interface	Description
	1. Locate the first image series (For example, PET (E12)/1 in the left panel)) in the Palette Explorer, Dataset Browser or Workspace Explorer and Right-click the selected image series in the Palette Explorer, and select Image Fusion
	2. A new Image Fusion Window is opened with the image series from step 1 loaded. Additionally, a windowing and analysis toolbox is displayed for adjusting the image contrast and transparency
	3. Locate the second image series (For example, Flash (E11)/1 in the left panel)) in the Palette Explorer and drag it into the Image Fusion window to load it as an overlay or as a base image
	4. The PET and MR datasets are automatically fused. Adjust the image contrast using the look up table and the filters to get the desired fused image. Additionally, use the Volume Visualization settings and the Clipping or Cutting function to go through the dataset and work on a cross-section in the 3D viewer. Future versions will include options for saving and exporting the fused images.

5. The current layout settings and the state of the palette can be saved as a Preset by going to the Fusion menu and saving the Preset

Intensity Based Registration

At times the animal or sample may have shifted between the PET and the MR acquisitions. This will result in a geometric misalignment between the two datasets (Figure 1) that will be visible after applying the Image Fusion workflow described in table 2. Thus, it is useful in this case to improve the geometric alignment between the two datasets by using the Intensity Based Co-registration functionality. Intensity-based image registration is a process that searches for an affine transformation that aligns a source image dataset to a given reference by maximizing the mutual information between them. The algorithm is based on MIRIT (Multimodality Image Registration using Information Theory) software technology developed at KU Leuven [2, 3].

The registration process requires two image series; one as the source and other as the reference. After the registration process is complete, a new image series is created, aligned with the dimensions of the reference image series. Table 2 shows the ParaVision360 workflow to set up an image registration process after the source and reference image series have been acquired.
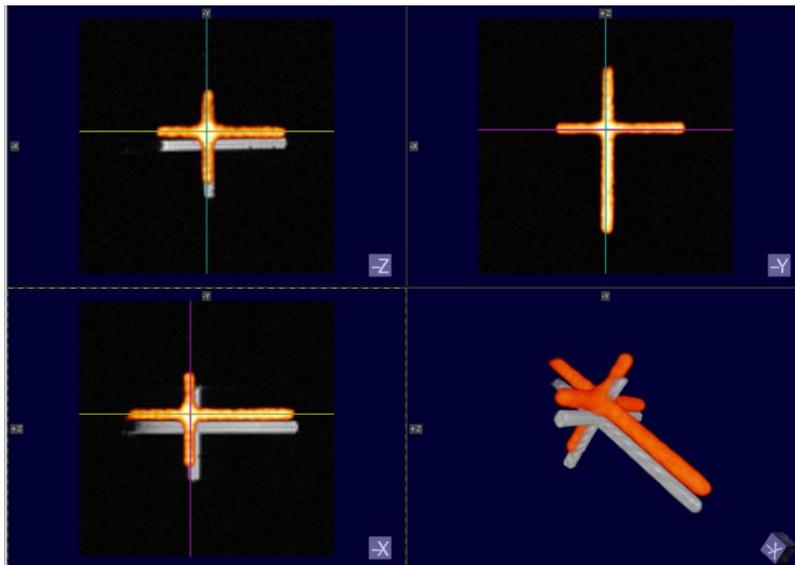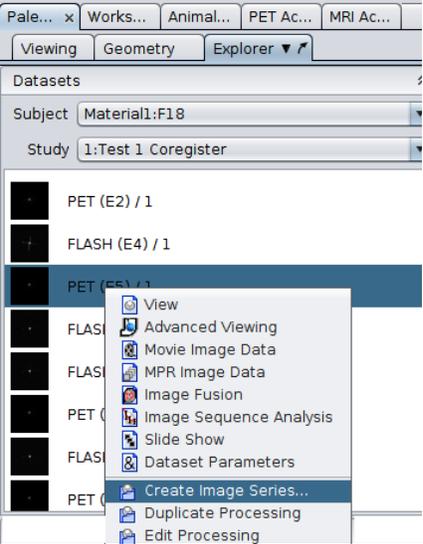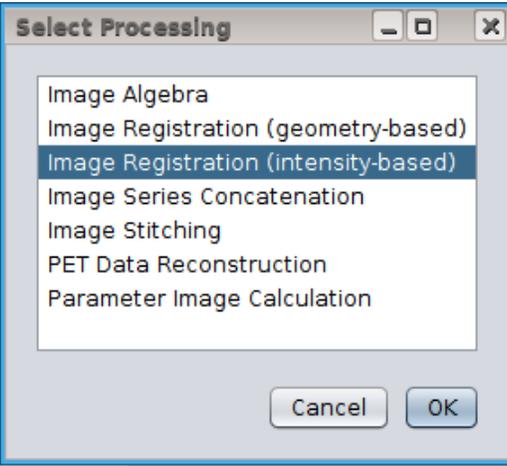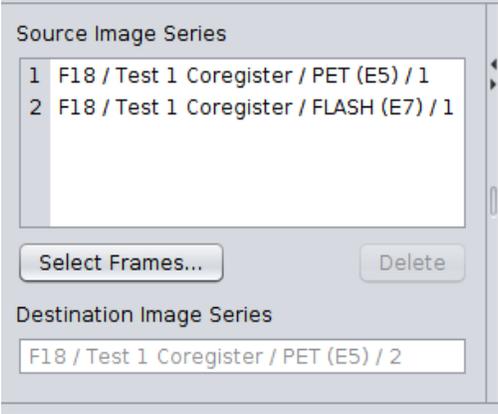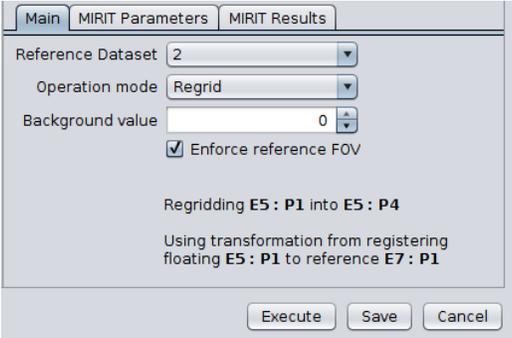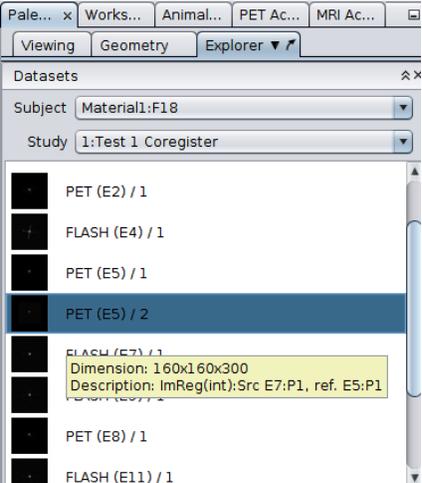

Figure 1: Geometric misalignment between the PET and MR datasets. Such a misalignment can be automatically corrected using the image registration workflow described in table 2

Table 2: ParaVision360 workflow to set up an image registration process after the source and reference image series have been acquired

ParaVision360 Interface	Description
	1. Locate the source image series in the Palette Explorer, Dataset Browser or Workspace Explorer and Right-click the source image series, and select Create Image Series
	2. Select Image Registration (Intensity Based) and click OK. The corresponding processing editor shows up (see Figure 2 for details)
	3. Locate the reference image series in the Palette Explorer, Dataset Browser or Workspace Explorer and drag it onto the list of input image series in the Image Registration Processing Editor.

	4. Adjust parameters as desired (refer Figure 3 for details). Check that the choice of reference image series is correct. Click Execute.
	5. A new image series is created below the source image series with a description giving information about the type of registration, the source and the reference image series used. For example, "ImReg(int): Src E7:P1, ref. E5:P1"

To determine how the resulting affine transformation is applied to the source image dataset, the main card of the Processing Editor contains two operation modes (Figure 2)

- **Regrid:** In this mode, the affine transformation is applied to the source image series and then the source is regrid to the geometry of the reference image dataset. Basically, this is an affine transformation followed by a geometry-based image registration.

- **Transform:** The affine transformation is applied to the source image series, but all the geometric parameters of the source are maintained. The reference image series is only used to determine the affine transformation.
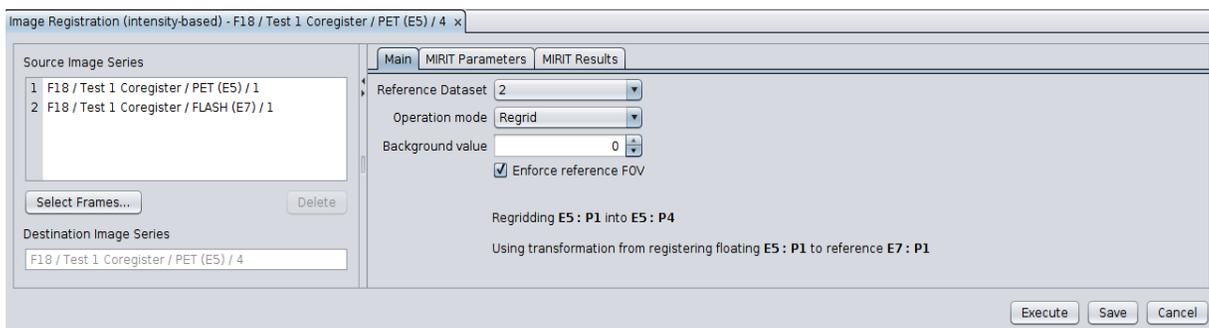

Figure 2: Main Card of the Intensity Based Registration showing the option for selecting the reference dataset, operation mode and background value MIRIT Parameters

The MIRIT Parameters Card of the Processing Editor (Figure 3) allows adjusting the parameters of the mutual information registration algorithm. The iterative search for the optimal affine transformation operates on three cascaded levels: The outermost loop is over several resolution levels, so that first the transformation is determined on sub-sampled versions of the images, to get rough estimates for the parameters. These are then used as initial values for the subsequent iteration on images with higher resolution. The last step always operates on the fully sampled images. On the second level, the free parameters are varied one by one in the given optimization order iteratively. Finally, in the innermost loop, an iterative line search is performed for each free parameter. In each iteration, the mutual information between the images is evaluated.
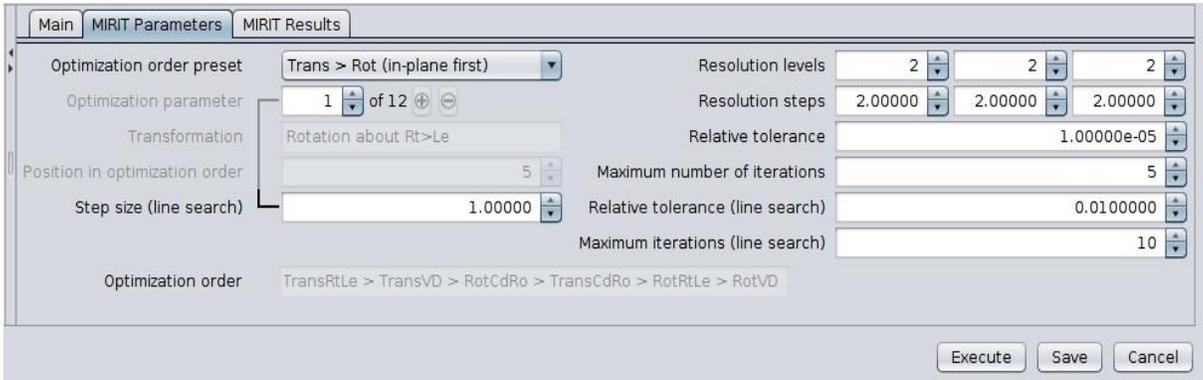

Figure 3: MIRIT Parameter Card showing the parameters that can be adjusted to optimize the image registration process

The transformation takes place in the DICOM subject coordinate system: First axis directed from R to L, second axis directed from A to P and the third axis directed from F to H. The twelve parameters of the affine transformation are: Rotations about each of the subject coordinate axes, translations along each of the subject coordinate axes, scaling and shearing in the direction of each of the subject coordinate axes. The order in which these parameters are optimized, and the respective step sizes can be configured in the left column of the MIRIT Parameter Card (Figure 3). Several optimization order presets are available but also a user-specific optimization order can be chosen, by setting the preset to User and explicitly specifying the position of each optimization parameter in the optimization order. If the position of a given parameters is zero, it is not included in the optimization. The selected optimization order is always displayed in full detail on the bottom line of the MIRIT Parameters Card. In the right column, the resolution levels, sub-sampling steps and iteration and tolerance values for the second and third optimization levels can be specified.

In most cases, when the geometric misalignment is not too large, the default setting is sufficient to find the correct transformation. However, in cases where the misalignment is substantial, the registration might fail. In this case, try to increase the step size for the parameter that needs the largest adjustment, or use a preset in which this parameter was optimized previously.

MIRIT Results

Figure 4: MIRIT Results card showing the results obtained after the transformation

When an intensity-based image registration processing has finished, the affine transformation that has been applied can be accessed by right-clicking the finished processing in the Palette Explorer and selecting Edit Processing. The MIRIT Results Card will display the result of the MIRIT optimization (Figure 3)

An in-vivo example of the application of the Image fusion function of ParaVision360 is shown in figure 5. A Mouse with neuroblastoma tumor in the adrenal gland was measured with a sequential PET/MR system, MR Turbo sequence followed by an FDG PET acquisition of 60 min.
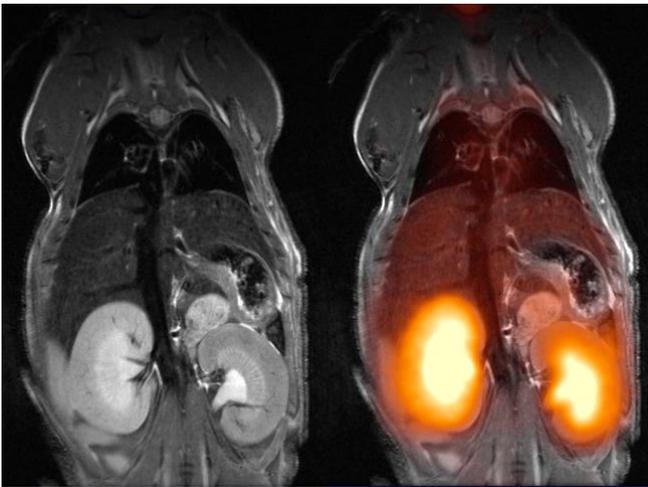

Figure 5: On left is the MR image and on right is the PET image overlaid on the MR data by using the automated image fusion tool in ParaVision360. *(Data courtesy of Dorde Komljenovic, Mark Ladd, Medizinische Physik in der Radiologie, DKFZ, Heidelberg, Germany).*

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