Image fusion, background, theory, pitfalls and artefacts

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In nuclear medicine, Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) are widely used for diagnostic investigation, primarily in oncology but also in cardiology and neurology as well as for radio therapy planning. The lack of structural information in nuclear medicine makes it difficult to assess the precise location of tissue with metabolic uptake, whereas Magnetic Resonance (MR) and Computed tomography (CT) can provide great anatomical details. By fusing PET or SPECT datasets with images of anatomy we can create images that can provide the best of both worlds: multi-modality imaging where functional information and structural location provides information for a given diagnostic or research situation.

Image fusion, defined as integration of two or more images into a single dataset, is achieved in a two-stage process. Firstly, images are registered or matched – in this process one dataset, typically a functional image, is mapped to another image, typically an image containing structural information. Thereafter, images are "fused" by superimposing the images and blending the image intensity values to create the combined image.

The registration stage has a lot of challenges, it requires establishment of a coordinate transformation between the two images that will map points of the same anatomical location to each other. In this process we have to account for differences in slice thickness and position, differences in beds, positioning, patient motion etc. and when fusing image data over time, also changes in anatomy, tumor size, organ motion, breathing, bowel motion, bladder etc.

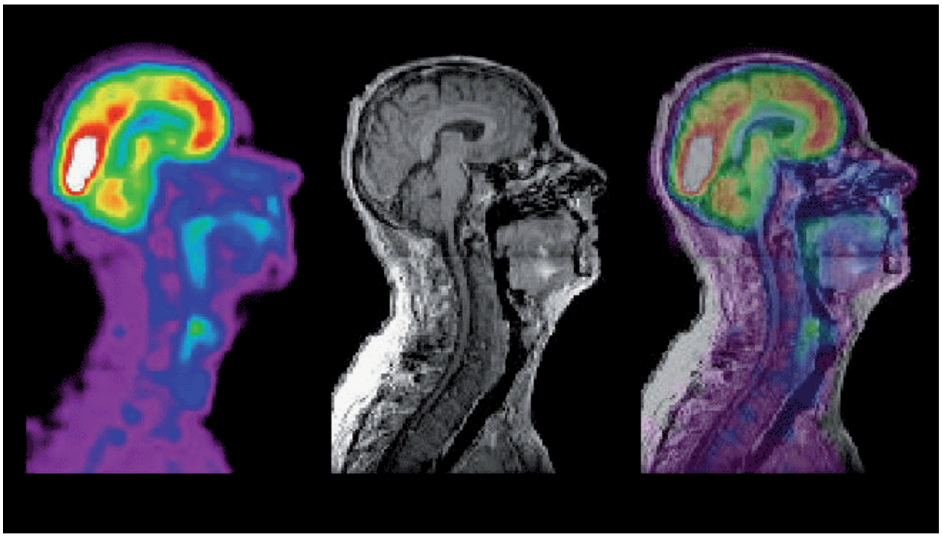

Figure 1: Example of image fusion where the PET bed has been reshaped prior to scanning to match the MR-neck coil.

The optimal choice for image fusion is to use hybrid scanners, SPECT/CT or PET/CT, as they provide a pixel-by-pixel mapping directly between the two datasets, but good positioning, use of various immobilization techniques, tush or tattoo markers are nice tool to achieve a good result. In the case of hybrid scanners, registration error can still appear when there is patient motion between the two scans. This is often seen as head movement, or differences between the CT "snapshot" of the liver/lung compared to the slow functional image.

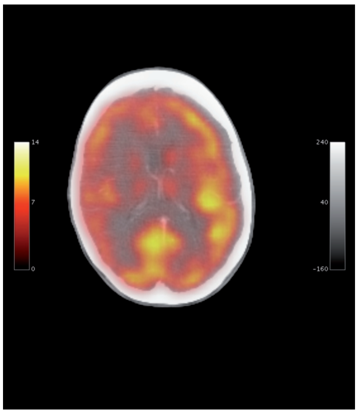

Figure2: Mis-registration of PET and CT image data on af PET/CT scanner due to head movement between scans.

Registration can be facilitated using a stereotactic frame or mask, or applying fiducial markers, but often we use the image data to achieve the registration. Examples of registration methods:

Manual registration.

- Identification of matching anatomical landmarks in the two dataset.
- Identification of external fiducial markers.
- Manual rotation and translation of images in order to achieve a match.

Automatic registration.

- Surface matching – minimizing distances between surfaces or volumes between surfaces.
- Iterative methods estimating a "cost function" - a measure of difference in location of the two datasets using mutual information, intensity cross-correlation, minimizing of the variance of the ratio between volume intensities etc.

A number of transformation types are available and depending on the task the right transformation type should be chosen. The simple "rigid body" transformation is often used when there is little difference in the two images, same patient, same day, similar bed. It only allows for rotation and translation of image data and only 6 parameters are matched (3 rotation axis and 3 directions of translation). By adding more parameters to allow for scaling and shearing of the image data, a better fit can be achieved when the difference between image data is large, i.e. long time between scans ore even different patients data, and in the case of soft tissue, deformation using non-linear matching should be considered. In general, the more freedom in the registration the more parameters will have to be fitted and in the case of manual matching, the more landmarks will have to be identified.

As the main problem with image fusion is mis-registration, how do we then define a good match? We can look at homologous point, do they match ? Organs of interest should overlap correctly. Measures of RMS distance between points, cost function values, residual distance and space between surfaces can be good guidelines, but only a careful visual inspection of the fused images by a trained person can validate the registration.

References

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