MRI TO PET-CT CO-REGISTRATION AND DIFFERENTIAL ANALYSIS

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Abstract: Analysis of parametric images (e.g. in MRI-DSC or dynamic PET) can be improved by their reference to structural images CT/MRI. This work compares different methods of geometrical transformations for image registration and normalization. Appropriate method for MRI to PET-CT image registration and normalization (in reference to atlases) is extremely important for common visualization of structural and parametric images in MRI and PET studies. Rigid and elastic geometrical transformations are implemented and compared. Additionally Delaunay triangulation and image morphing methods are used. Manual and proposed automatic registration and normalization methods are presented and compared based on MRI/PET and Talairach atlas images. Concluding, the proposed automatic image normalization method is accurate and using the combination of Delaunay and morphing methods can produce even better results.

Introduction

PET-CT hybrid systems offer new value in the market of diagnostic imaging: integrated structural (CT) and functional imaging (PET). Assuming integrated scanners (PET-CT) the patient position is fixed, so multimodal image can be constructed as a result of co-regitration of CT and PET images. However, especially in brain studies, the very important information is additionally carried by different MRI procedures, including as well structural as functional imaging. In this paper we present methods of MRI to PET-CT registration and visualisation for differential analysis.
Parametric imaging is more and more popular in dynamic brain studies [1][2]. It enables to quantitatively or semi-quantitatively estimate physiological state and processes in brain. Parametric images represent spatial distribution of parameter values calculated for chosen mathematical model of the process or object. Usually parametric images are calculated for dynamic studies, thus represent functional aspects of brain tissues and activity. Functional and parametric images should be usually refer to anatomy for needs of diagnostics or surgery. This is usually performed using combined modalities like CT/PET, CT/SPECT or recently MRI/PET. However the hybrid MRI/PET scanner are currently new on the market and are limited in functionality. It is important then to analyze methods for image to image registration and image to atlas normalization. Currently, this is a very active area of research [3][4].
In this study we would like to focus on geometrical transformation methods comparision, image to image registration and image to atlas normalization using manual and automatic methodology. The work is focused on CT/MRI/PET images both structural and functional (dynamic studies).

Material

PET-CT brain data were acquired for oncological patients (Biograph, Siemens, 18FDG). Additionally MRI studies (in some patients including perfusion and diffusion) were performed. The target task is to analyze the correlation between PET-CT and MRI images.
Using own system (created in Java programming language) all image series (PET/CT/MRI) were compared in separate panels. Additionally multimodal image is required (thus image registration). Since the PET-CT data are co-registered by hybrid scanner system, the MRI registration was performed in reference to CT structural data. All data files were stored in original file format (DICOM 3.0).

Geometry transformations

Global and local (free form deformations) geometry transformation methods were investigated.
In case of global geometry transformations the affine transformations and elastic transformations (i.e. polynomial transformations) were analyzed.
Affine transformations are described by the following matrix formula:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} r_{00} & r_{01} & t_x \\ r_{10} & r_{11} & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}; \quad (1)$$

where:
- t – translation vector,
- r – rotation/scaling matrix,
- {x’, y’} – transformed {x,y} coordinates.

Polynomial transformation can be described by specification of a_i, b_i parameters:

 ISSN: 1727-1983

$$x' = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2 + ... + a_j x^n + a_{j+1} x^{n-1} y + ... + a_{k-1} xy^{n-1} + a_k y^n$$
$$y' = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 + ... + b_j x^n + b_{j+1} x^{n-1} y + ... + b_{k-1} xy^{n-1} + b_k y^n \quad (2)$$

Finding appropriate control point pairs it is possible to automatically calculate transformation parameters and use them for an image geometry transformation.

Local geometry transformations were tested for the Delaunay triangulation and for the morphing transformation. Delaunay method is based on triangles generation inside an image plane: for a template and for a target image. Then triangles are compared and transfomed (locally by affine transform). As a result a image part covered by each triangle is copied to the output (transformed) image. Morphing transform (used in this tudy) is based on the line segment comparision between template and transformed images. Particular line is represented by two points Q and P in transfomed image. Corresponding line in a template image is described by points Q' and P' (Fig. 1.)

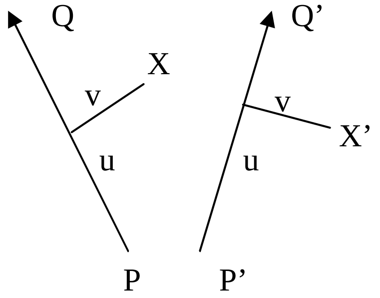

Figure 1: Corresponding lines description in morphing transformation

Transformation between a pair of lines can be described as:

$$u = \frac{(X-P)\bullet(Q-P)}{\|Q-P\|^2}, \quad v = \frac{(X-P)\bullet Perpendicular(Q-P)}{\|Q-P\|}, \quad (3)$$

$$X' = P' + u \bullet (Q'-P') + \frac{v \bullet Perpendicular(Q'-P')}{\|Q'-P'\|} \quad (4)$$

where:

$a \bullet b$ is given by *a.x*b.x + a.y*b.y*,
||a|| is given by $a.x^2 + a.y^2$,
Perpendicular(a) returns a point *(-a.y,a.x)*,

Calculated *u* value is a position along a line; *v* represents distance from a line.

If inside processed images are more than one line then each point is weighted based on the distance of the processed point from a given line, calculated as

$$weight = \left(\frac{length^p}{a+d}\right)^b, \quad (5)$$

where:

length – a line length,
d – distance,
a,b,p – constants.

Method

In our research we implemented DICOM data processing methods (PET/CT/MRI) and geometry transformation methods described above. Geometry transformation requires to define control points based on which is possible to calculate tranformation formula parameters. We developed and implemented manual and automatic method of image registration and normalization.

Image registration

Manual image registration is based on defining corresponding points in template and transformed images. The alternative method is to use predefined transformation formula parameters and type them into an appropriate configuration dialog window or a file. Using Java programming language we implemented a portable software based on two image panels: source and target. First the operator can chose between different geometry transformation methods: affine, elastic (2nd degree polinomial), elastic (n-degree polinomial), Delaunay traingulation and morphing transform. Then image template and transformed image have to be chosen (DICOM and popular image file formats are supported). After control point specification the operator can define other parameters, e.g. image interpolation method (nearest neighbor, bilinear, cubic convolution). The table below image panels presents (Fig. 2) source and target points coordinates and calculated root mean square errors for each point. Finally the operator can start the transformation and as a result it obtains a multimodal (registered) image with additional (optional) transformation grid presentation. An example of the software graphical user interface is presented in Fig. 2.

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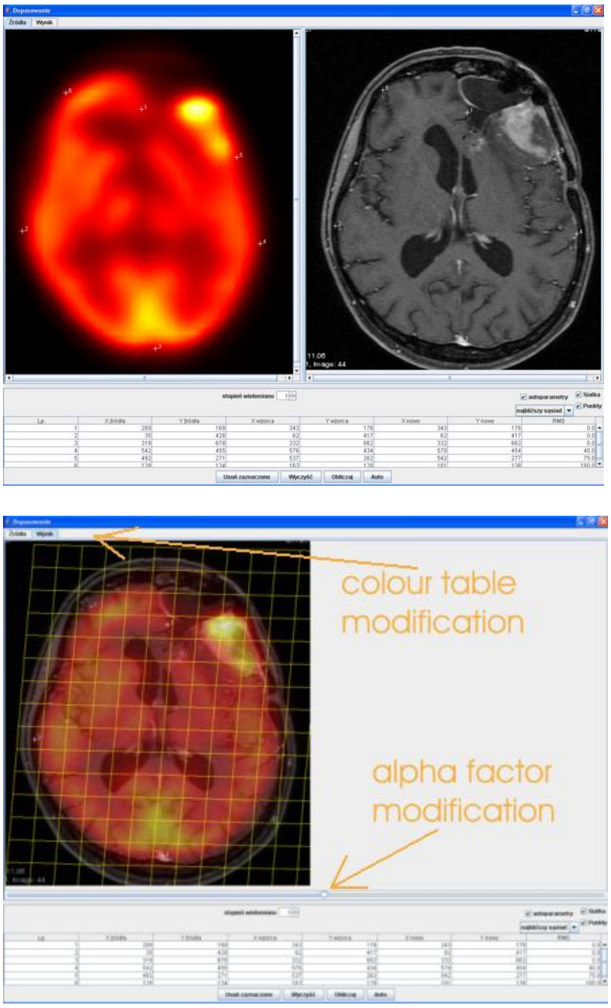


Figure 2: An example of the software graphical user interface used for manual control points definition and image registration

In case of image normalization the automatic method is proposed. First it is assumed that a template image is an Talairach atlas image [5]. The source image is either MRI (structural or parametric) or PET. At the beginning image color tables are compared and fitted (a grayscale color table M2 is used in processing). Then images are thresholded (using automatic threshold estimation based on local gradients [6]) and the surrounding background is eliminated using image binarization. Separate points elimination is performed using morpholocial closing operator. The next step eliminates a scalp and bones (if present). The automatic method is used based on gradient difference in thresholded MRI image (i.e., there is a strong difference between scalp/bone/brain, since the bone is not imaged by MRI). Then four characteristic points (edge points) are detected at North, South, West and East of the brain image. In the next step image is scanned top-down and left-right to find the external inner border points of a brain. The final set of points is reduced (if required) by eliminating those points which are close each other. Finally based on main object axis (a reference) for processed image and template atlas and using a set of border points the image is normalized to the atlas image.

Multimodal image visualization

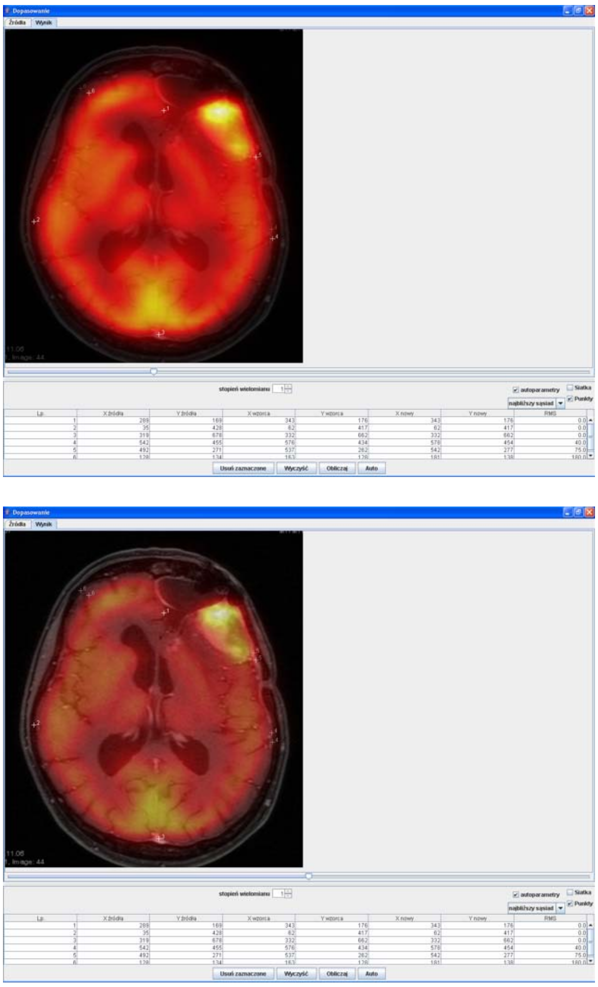
After image registration/normalization it is required to display them. Multimodal image visualization is implemented using alpha blending

$$c=(1-alpha)*a + alpha*b, \quad (6)$$

where:

c – new pixel value,
a,*b* – pixel values for a source image *a* and a target image *b*,
alpha – scaling factor (0..1).

Alpha blending is currently implemented as a global operation but now we are preparing the local alpha blending i.e. inside a Region Of Interest only. The alpha scaling factor can be defined using graphical scaling bar so the result image is generating interactively (Fig. 3).



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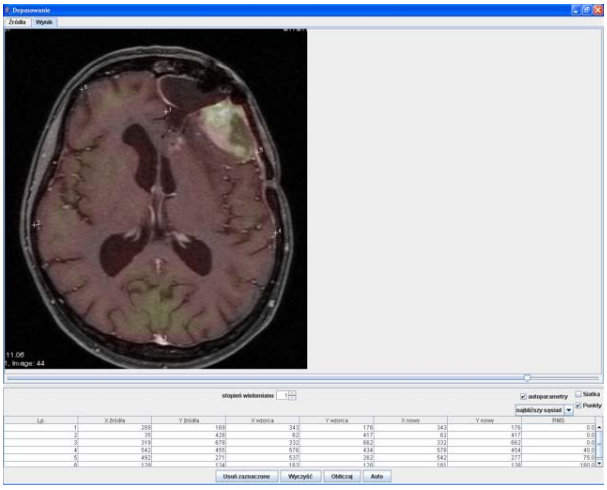

Figure 3: Multimodal image for different alpha scaling factor values

All implemented methods were verified using a test set. Test images were constructed based on original MRI image, PET image and atlas-derived image (Fig. 4).

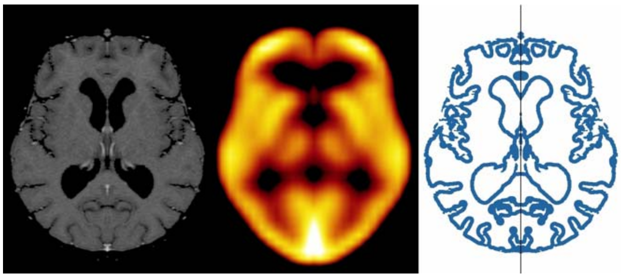

Figure 4: Test images - original MRI image, PET image and atlas-derived image

Using original set of images a series of geometrically modified images was generated. MRI and PET images were modified by eleven different affine and perspective transformations. The total number of images in a test set was 24.

Results

All images from a test set were processed to fit the atlas image. Different geometrical transformations were investigated, but a special attention was putted on affine transformation, Delaunay triangulation and morphing transformation. As a measure of normalization quality a difference image (i.e. compared to an original image) was generated. Difference images were constructed using negative greyscale (dark points for higher values). Figure 5 presents results obtained for automatic image normalization using different geometry transformation methods. Presented examples were generated for the same images (MRI/PET) from the test set (i.e. scaled original images).

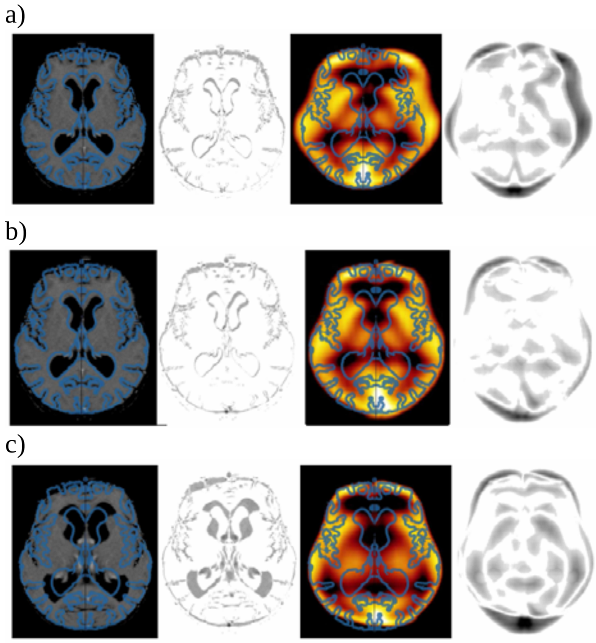

Figure 5: Results of automatic image normalization for scaled MRI/PET source images using: a)affine transform, b) Delaunay triangulation and c) morphing transform

Taking into account all tests the affine transform gave the worse results. It could be expected since affine transform is based only on 3 control points, thus it register images accurately in the neighbourhood of control points (i.e. locally). Using Delaunay triangulation much better results were achieved. Of course higher number of triangles (control points) leads to better normalization quality. However using automatic method (without artificial markers) it is very difficult to find many control points. In many cases morphing transform produced much better results than Delaunay transform. This is highly related to compared objects sizes – if two objects are similar (in case of scale) then the morphing method works more accurately than Delaunay transform. This is a reason of high normalization errors for morphing transform presented in Fig. 5 (50% smaller images are normalized to original atlas image). Some examples of automatic normalization of MRI and PET images are presented in figures 6 and 7.

Tests were performed on two different workstations: Intel Pentium III, 600 MHz, 512 MB RAM, FreeBSD 5.4 and Pentium 4 3.2GHz, 2GB RAM, Windows XP. Average times required for automatic normalization on the first (old) machine were: 20s for affine transform, 40 s for Delaunay transform and 88s for morphing transform. Tests performed on the second machine were much faster: 3.5s for affine transform, 6.2s for Delaunay transform and 12.5s for morphing transform. All software modules were written in Java programming language. All tests were performed using Java Runtime Engine 1.5.

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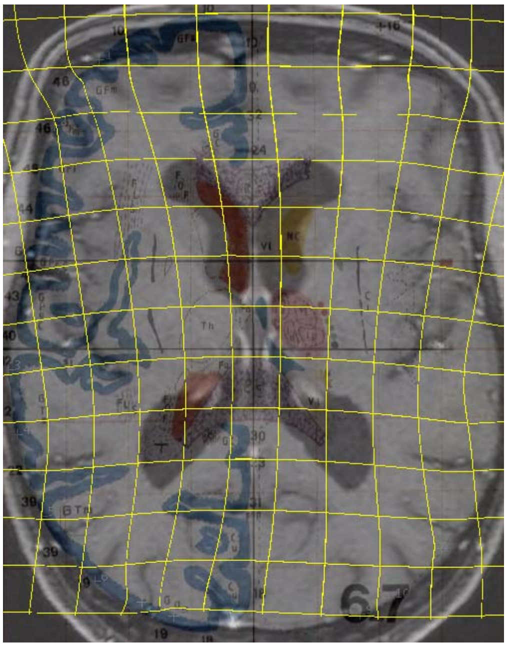

Figure 6: An example of automatic MRI image normalization.

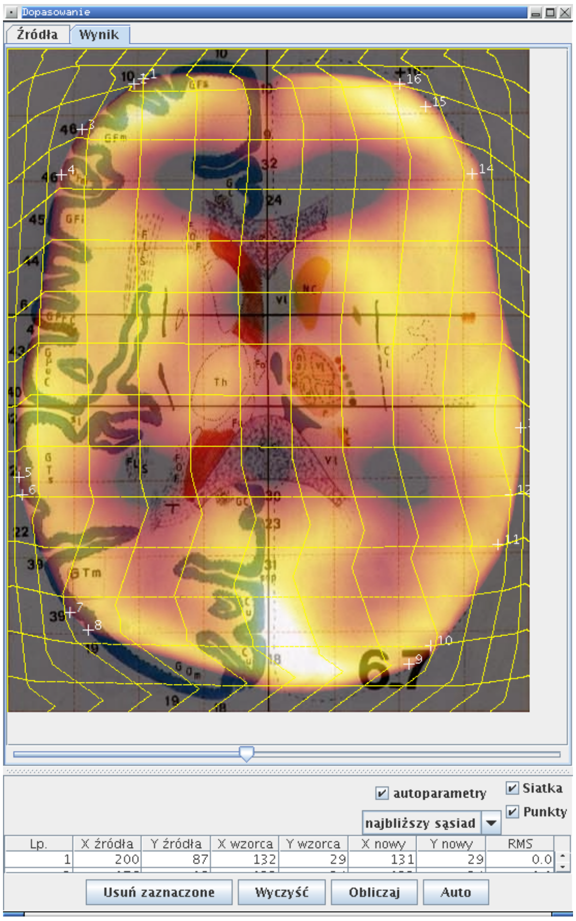

Figure 7: An example of automatic PET image normalization.

Discussion and conclusion

Results indicates that the automatic normalization of images is not a trivial problem. Even in case of manual control points specification for test images the registration process (for every analyzed method) produces errors. The automatic method using morphing transform and Delaunay transform gave similar results that those obtained for manual control points indication by an expert. Important conclusion of the research is the requirement of combined transformation methodology: first applying Delaunay transformation to fit a scale of the target image (atlas) and then using morphing transform to improve the quality of the registration.

Using combined presentation of registered or/and normalized images, i.e. as a multimodal image or separate images, it is much easier to compare particular patients studies or to judge about usefulness of particular modality in diagnosis of a disease. This is especially important in case of PET since its cost and radiation problems.

Described methodology and software are implemented as a part of the parametric imaging framework for brain studies. The target software package is prepared to analyzed dynamic MRI and PET data, to combine them in one common view, especially in case of parameter images which describes dynamic changes in brain. In figure 8 the example of the graphical user interface is presented with brain images.

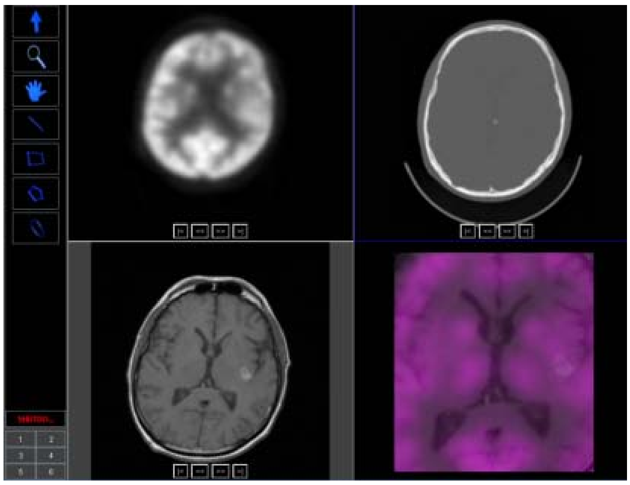

Figure 8: Examples of the integrated parametric imaging package: PET, CT, MRI and co-registered PET to MRI images

In most cases global co-registration was sufficient in the opinion of experts. Using presentation context manipulation (for both input images: window, color table) MRI to PET data comparisons were possible. Medical conclusions were very interesting, suggesting that 18FDG PET improves the diagnostic value only in malignant and primary tumors. In some cases (e.g. metastasis) 18FDG PET did not provide any results while the MRI did. According to experts requirements the additional software tool was created to improve

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local (near tumor), manual co-registration. The software allows to open PET/CT/MRI images in DICOM format, and manually select number of control points. The very interesting conclusion is that the manual points selection for local co-registration was often preferable, giving better control to specialists with the limited extra operations required.

Acknowledgements

The work was partially supported by the Polish State Committee for Scientific Research, grant No 4 T11E 042 25, 2003-2006).

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ISSN: 1727-1983