MEDICAL IMAGE REGISTRATION IN MATLAB

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ABSTRACT

Biomedical imaging based on different physical principles has played a more and more important role in medical diagnosis. Multiform methods of image diagnosis provide doctors and clinicians with various anatomical and functional information to carry out exact diagnosis and effective treatment.

Image registration is the process of combination the different sets of data of the same object, which come from different modalities (CT, MRI, SPECT, PET etc.). Pre-processing algorithms improve image quality and image registration algorithms transform the object of images into one coordinate system. As a result, registered image would be more informative than original images. At the present time, many registration problems still remain unresolved or not optimal. This paper introduces some improvements and illustrated implementation in MATLAB.

KEY WORDS

Biomedical imaging, registration, subtraction, image processing, Matlab.

1. Introduction

Nowadays, medical image diagnosis is considered as one of the fields taking advantage of high-technology and modern instrumentation. DSA, Ultrasound, CT, MRI, SPECT, PET etc. have played an important role in diagnosis, research, and treatment. In general, there are two basic types of medical images [1]: functional images (such as SPECT or PET scans), which provide physiological information, and anatomical images (such as X-ray, Ultrasound, CT or MRI), which provide anatomic structure of the body. Therefore, doctors could only study structure or function of the object separately and in many cases they meet with difficulties to diagnose correctly.

These instruments have been greatly assisted by information technology. By digital acquiring, displaying and processing, high accurate detailed images have been produced. Not only does information technology help to reconstruct images, but it also helps to improve the image quality. Based on mentioned improved images, doctors and clinicians are able to make a more exact diagnosis than in cases of using traditional imaging modalities based on analog technology.

Registration is one of mentioned digital processing advanced technique: by using appropriate computational algorithms, a mapping (transformation) between two images spatially and with respect to

intensity can be found to produce a new informative image which has both of functional and structural information. This would help clinicians faster and more effective diagnosis.
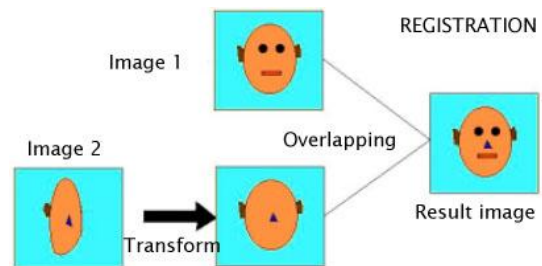

Fig.1 : The concept of registration [2]

There are some practical application fields of registration [2]:
- Integrating information taken from different sensors (Multimodal registration)
- Finding changes in images taken at different times or under different conditions (Temporal registration)
- Inferring three dimensional information from images in which either the camera or the objects in the scene have moved (Viewpoint registration)
- For model based object recognition (Template registration).

The first two application fields (registration of multimodal images & analysis of temporal evolution) will be concerned in this paper.

2. Method

Assuming that we have two images of the same object, a structural image and a functional image, the process of registration is composed of following steps:
- Ø Acquiring information from two images ;
- Ø Pre-processing to improve the quality of images ;
- Ø Selecting the same characteristics and finding a mapping between two images to find out transformation functions ;
- Ø Reconstructing images based on above functions ;
- Ø Combining reconstructed images by overlapping them with an appropriate transparency (registration of multimodal images) ;
- Ø Subtracting reconstructed images from original images (analysis of temporal evolution).

2.1 Image acquisition

Images of a patient obtained by CT, MRI and SPECT, PET scanning are displayed as an array of pixels (a two dimensional unit based on the matrix size and the field of view) and stored in memory.

In Matlab, there are several formats of image encoding [3]:

- Binary images

Large matrix whose entries are one of two values will specify a black and white image. 0 corresponds to black, 1 to white.

- Greyscale or **intensity images**

A greyscale image can be specified by giving a large matrix whose entries are numbers between 0 and 1, with 0 corresponding, say, to black, and 1 to white. A black and white image can also be specified by giving a large matrix with integer entries. The lowest entry corresponds to black, the highest to white. In Matlab, this matrix would be of class uint8 or uint16.

- Indexed images (intensity images with colormaps)

Given a large matrix A with integer entries ranging from 1 to M, one can color the (i,j) pixel of the image according to the RGB (red-green-blue) intensities in row A(i,j) of a colormap matrix map, which is an M by 3 matrix.

- RGB or **Truecolor images**

An RGB or truecolor image is specified by telling three matrices, one for the intensity of red, one for green, one for blue (hence the acronym RGB). In Matlab, a matrix can have more than two indices. A(:,:,1) would refer to the first matrix, the one for red, A(:,:,2) for green, and A(:,:,3) for blue.

- NTSC images

This is another way of coding the colormap mentioned above. Instead of red-green-blue, it uses luminance and a two-dimensional chrominance. It's still three variables.

2.2 Image Pre-processing

To find out a transformation between two images precisely, they should be pre-processed to improve their quality. If these images are too noisy or blurred (caused by instruments or patient's moving while scanning), they should be filtered and sharpened.

2.2.1 Filters [4]

In image processing, filters are mainly used to suppress either the high frequencies in the image, *i.e.* smoothing the image, or the low frequencies, *i.e.* enhancing or detecting edges in the image. An image can be filtered either in the frequency or in the spatial domain.

The first involves transforming the image into the frequency domain, multiplying it with the frequency filter function and re-transforming the result into the spatial domain. The filter function is shaped so as to attenuate some frequencies and enhance others. For example, a simple lowpass function is *1* for frequencies smaller than the *cut-off frequency* and *0* for all others.

The corresponding process in the real domain is to convolve the input image f(i,j) with the filter function h(i,j). This can be written as

$$g(i,j) = h(i,j) \odot f(i,j)$$

The mathematical operation is identical to the multiplication in the frequency space, but the results of the digital implementations vary, since we have to approximate the filter function with a discrete and finite mask (kernel).

The discrete convolution can be defined as a `*shift and multiply'* operation, where we shift the kernel over the image and multiply its value with the corresponding pixel values of the image. For a squared kernel with size M× M, we can calculate the output image with the following formula:

$$g(i,j) = \sum_{m=-\frac{M}{2}}^{\frac{M}{2}} \sum_{n=-\frac{M}{2}}^{\frac{M}{2}} h(m,n)\, f(i-m, j-n)$$

Various standard kernels exist for specific applications, where the size and the form of the mask determine the characteristics of the operation.

Mean filtering is a simple, intuitive and easy to implement method of *smoothing* images, *i.e.* reducing the amount of intensity variation between one pixel and the next. It is often used to reduce noise in images.

The median filter is normally used to reduce noise in an image, somewhat like the mean filter. However, it often does a better job than the mean filter of preserving useful detail in the image.

The Gaussian smoothing operator is a 2-D convolution operator that is used to `blur' images and remove detail and noise. In this sense it is similar to the mean filter, but it uses a different kernel that represents the shape of a Gaussian (`bell-shaped') hump.

2.2.2 Brightness and contrast adjustment

Histogram processing [5]: Histogram is the basis for numerous spatial domain processing techniques. Histogram manipulation can be used effectively for image enhancement. The horizontal axes of each histogram plot corresponding to gray level values, r_k. The vertical axis corresponds to values of $h(r_k) = n_k$ or $p(r_k) = n_k / n$ if the values are normalized.

In the dark image, the components of the histogram are concentrated on the low side of the gray scale. Similarly, the components of the histogram of the bright image are biased toward the high side of the gray scale. An image with low contrast has a histogram that will be narrow and will be centered toward the middle of the gray scale. Finally, we see that the components of the histogram in the high-contrast image cover a broad range of the gray scale and, further, that the distribution of pixels is not too far from uniform, with very few vertical lines being much higher than the others.
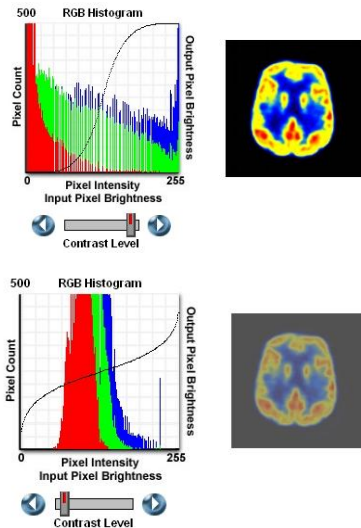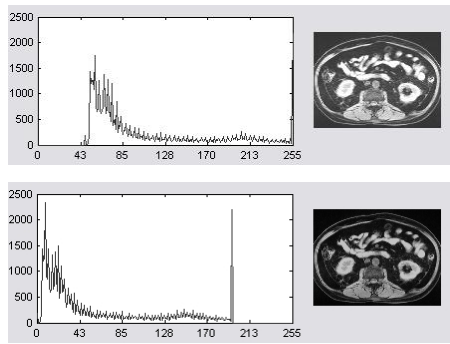
Fig.2 : Four basic image types : light, dark, high-contrast, low-contrast and their responding histogram.

2.3 Finding a transformation between two images

A spatial transformation maps locations in one image to new locations in another image.

Determining the parameters of the spatial transformation needed to bring the images into alignment is the key to the image registration process.

- Point mapping: In point mapping, we pick points in a pair of images that identify the same feature or landmark in the images. Then, a spatial mapping is inferred from the positions of these control points.
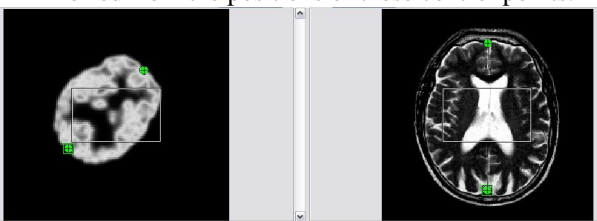
Fig. 3 : Point mapping

- Region mapping: CT and MRI images in most cases have discriminated regions. For example, bone region in CT images could be distinguished easily from tissue region by using threshold algorithms.
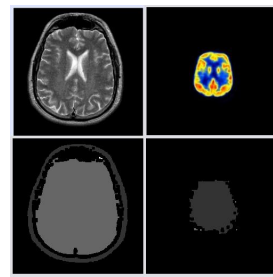

Fig. 4 : Region mapping

A spatial transformation modifies the spatial relationship between pixels in an image, mapping pixel locations in an input image to new locations in an output image. Here are some spatial transformation types:

- Affine: Transformation that can include translation, rotation, scaling, and shearing. Straight lines remain straight, and parallel lines remain parallel, but rectangles might become parallelograms.
- Projective: Transformation in which straight lines remain straight but parallel lines converge toward vanishing points. (The vanishing points can fall inside or outside the image -- even at infinity.)
- Box : Special case of an affine transformation where each dimension is shifted and scaled independently.
- Composite : Composition of two or more transformations.

To reduce the time consuming in finding a transformation between two images, multi-resolution and multi-grid approaches is introduced [6]. At each level of resolution, we use a multi-grid minimization based on successive partitions of the initial volume. At each grid level, corresponding to a partition of cubes, we estimate a 12-dimension parametric increment field for each cube of the partition. The energy is consequently smoother, and has fewer local minima. This result is a rough estimate of the desired solution, which is then used to initialize the next level.
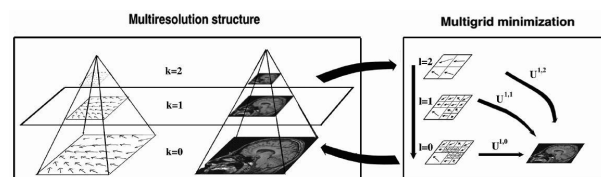

Fig.5: Example of multiresolution/multigrid minimization. For each resolution level (on the left), a multigrid strategy (on the right) is performed.

2.4 Image Reconstruction – Interpolation method

Once a spatial transformation is established, we can proceed to reconstruct the image.

$$\begin{cases} X = f(x,y) \\ Y = g(x,y); \end{cases}$$ where (x,y) is the coordinate of a pixel on original image and (X,Y) is the coordinate of a pixel on transformed image.

In digital images, the discrete picture elements, or pixels, are restricted to lie on a sampling grid, taken to be the integer lattice. The output pixels, now defined to lie on the output sampling grid, are passed through the mapping function generating a new grid used to resample the input. This new resampling grid, unlike the

input sampling grid, does not generally coincide with the integer lattice. Rather, the positions of the grid points may take on any of the continuous values assigned by the mapping function.

Since the discrete input is defined only at integer positions, an interpolation stage is introduced to fit a continuous surface through the data samples. The continuous surface may then be sampled at arbitrary positions. This interpolation stage is known as image reconstruction.

The accuracy of interpolation has significant impact on the quality of the output image. As a result, many interpolation functions have been studied from the viewpoints of both computational efficiency and approximation quality. Popular interpolation functions include cubic convolution, bilinear, and nearest neighbor. They can exactly reconstruct second-, first-, and zero-degree polynomials, respectively. More expensive and accurate methods include cubic spline interpolation and convolution with a sine function.
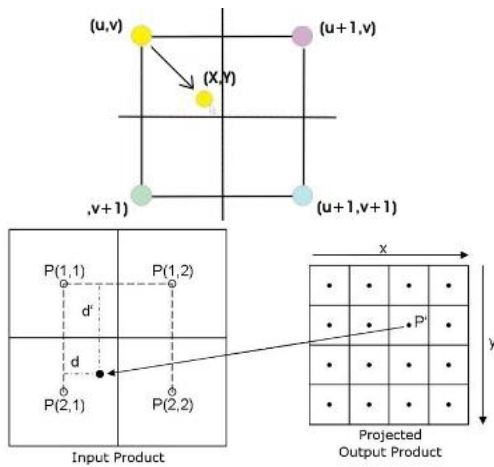

Fig.6: Interpolation (a) nearest neighbor (b) bilinear

2.5 Combining reconstructed images

Images after being reconstructed are combined by overlapping at an appropriate transparency. In fact, every pixel value from the result image is a combination of all pairs of corresponding pixel values from base and reconstructed images with a coefficient (trans) which determines the transparency.
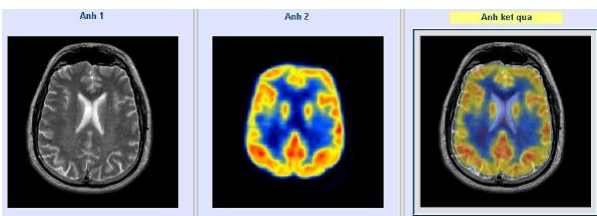

Fig.7 : Overlapping images

$result\_img(i,j,k) = (1\text{-}trans)*base\_img(i,j,k)+ trans* constructed\_img(i,j,k)$

2.6 Subtracting images [5]

The difference between two images f(x,y) and h(x,y), expressed as:

$g(x,y) = f(x,y) - h(x,y)$

is obtained by computing the difference between all pairs of corresponding pixels form h and g. The key of usefulness of subtraction is the enhancement of differences between images. In order to bring out more detail, we can perform a contrast stretching transformation such as histogram equalization.

One of the most commercially successful and beneficial uses of image subtraction is in the area of medical imaging called mask mode radiography (DAS) or analysis of temporal evolution (from CT, MRI, SPECT, PET images)
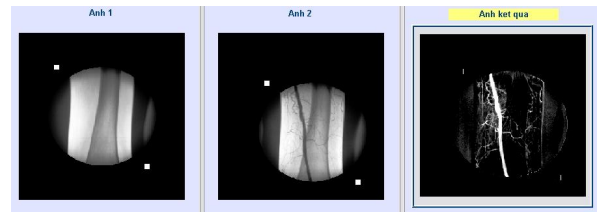

Fig.8 : Subtration images (a) Mask image (b) Image taken after ejection of a contrast medium into the blood stream (c) Image with mask subtracted out.

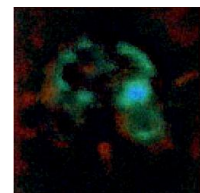Fig.9 : Subtracted ictal and interictal SPECT images

Fig.10: Result image with contrast stretching

## 3. ImagRegis – Registration software written in Matlab

Written and run in Matlab 7.0 (R14) environment, ImageRegis has been supported by Image Acquisition Toolbox 1.5, Image Processing Toolbox 4.2 (The MathWorks) and IMUI – an Image Processing Toolbox Utility (Kotaimen Cao).

### 3.1 Features of ImageRegis
§ Medical image information display.
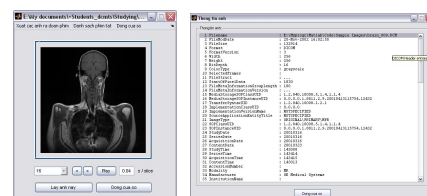
§ Image processing: Resize, resize canvas, crop, rotate, flip, noise filter, convolution, brightness / contrast, auto levels, levels, desaturation, invert, threshold, edge detection, color balance, hue and mixture.
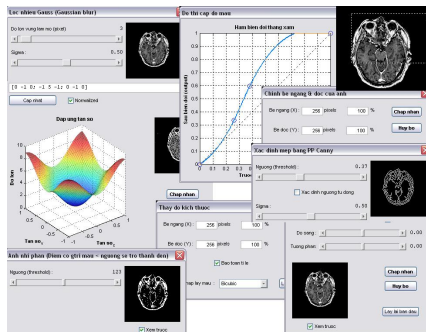
§ Registration of multimodal images:
- CT-SPECT registration
- MRI-PET registration
- MR-CT registration

Method: Manual (translate, rotate, resize image by hand), Semi-Auto (pick points in a pair of images that identify the same feature or landmark in the images) and Auto registration (perform automatically by program's algorithms)
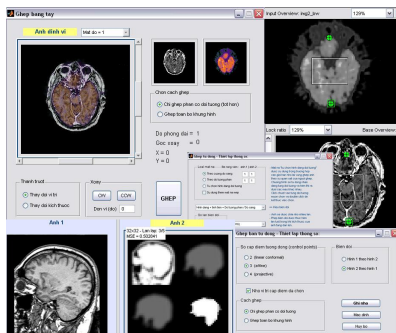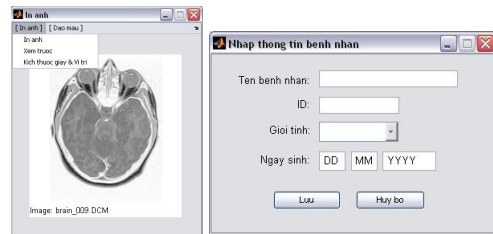

§ Analysis of temporal evolution or detection of difference:
- DSA subtraction
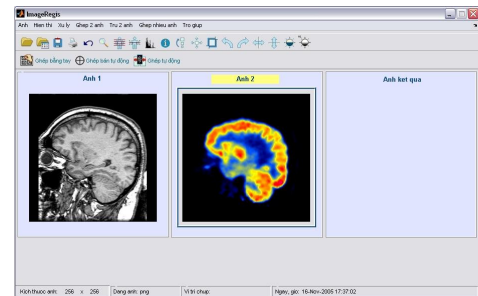- PET subtraction

Method: Manual and Semi-Auto Subtraction.
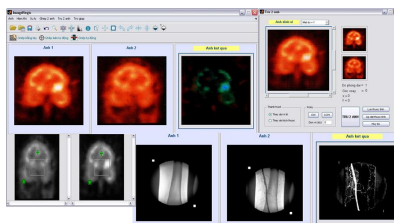
§ Export result images as DICOM, JPG, AVI files… or printing them.

3.2 User's interface:

In the main window, a menu bar, toolbar, status bar and three boxes displaying two input-images and a result image are used to operate.

[Image] menu: open images, DICOMDIR, save, print or open images in new windows.

[Display] menu: undo, zoom, grid display, pixel value, histogram, , contour, K-space, image's information or toolbar options.

[Processing] menu: resize image, resize canvas, crop, rotate, flip, filter, convolution, brightness /contrast, autolevels, levels, curve, desaturation, invert, threshold, edge detector and other features…

[Registration] menu: Manual, Semi-Auto, Auto, Fast Registration and method preferences.

[Subtraction] menu: Manual, Semi-Auto Registration and method preferences.

[Help] menu: Program's information, help and contacts

4. Discussion

The program is evaluated by these criteria:

a) Multi-purposes: image processing, registration of multimodal images and subtraction to analyze of temporal evolution.

b) Accuracy: Accuracy of the registration algorithm depends on the MSE value (auto-registration) or skill and experience of clinicians (manual / semi-auto registration). The geometrical errors could be introduced by the spatial resolution of the image (pixel size is equal to the field of view divided by the matrix of pixels) and algorithm of shape detection and interpolation function. Increasing the spatial resolution will increase the patient dose irradiation for CT image, and time examination for MRI. In general, compromise has to be taken between the quality of the images and patient welfare. It is clear that for each anatomical model sensitivity analysis has to be performed in order to define appropriate technical protocol of acquisition.

c) Speed: In general, the processing speed of the program is fast except auto-registration tool because it needs time to minimize MSE value.

d) Easiness: Program's interface is visual, detailed and easy to use. By grouping program's features into steps relied on image registration process, users are able to operate quickly and without difficulty.

e) Support: Detailed helping section is also included in the program. Educational toolkit is one of the goals of ImageRegis. Carefully noted source code of the program would help students understand syntax and algorithm of medical image registration. Besides, visual program interface could illustrate how to register medical images.

f) Restriction: the program is still running only in Matlab environment because until now it can't be compiled successfully with newest Matlab Compiler Toolbox (version 4.5).

5. Conclusions

Relevance of such techniques is the direct clinical application for registration. This provides a diagnosis and preoperative planning surgery (how an area is flooded, or to see where a tumor is visible in MRI and SPECT image…). Alternatively, it is a useful tool in image processing training.

Algorithms of finding a transformation between two images is of importance in the methodology; spatial and density resolution have to be achieved to reduce geometric errors.

The program needs to be compiled to run in an independent environment and algorithms need to be optimized in order to reduce the time consuming in performing and increase accuracy. The program could be developed in ability of access to host computer of hospital via intranet to get patients' information and images.

In Vietnam, application of information technology in medicine is just at the first step with many difficulties such as human resources, material facilities… Hopefully, this program may initially contribute to the development of medical software technology in Vietnam.

6. Acknowledgements

7. References

[1] KARIN KNEÖAUREK, MARIJA IVANOVIC, JOSEF MACHAC, DAVID A. WEBER**, Medical image Registration,** Division of Nuclear Medicine, The Mount Sinai Medical Center, New York, USA Department of Radiology, University of California at Davis, California, USA, Europhysics News (2000) Vol. 31 No. 4

[2] ZHIFENG CAI: **Medical Image Registration,** National Laboratory of Pattern Recognition (Institute of Automation, Chinese Academy of Sciences), 2003 *(http://nlpr-web.ia.ac.cn/english/iva/GroupMeeting/PPT/MedicalImageRegistration.ppt)*

[3] CRAIG L. ZIRBEL**: Matlab image types,** Department of Mathematics and Statistics, Bowling Green State University *(http://www-math.bgsu.edu/~zirbel/rfim/matlabimagetypes.html)*

[4] BOB FISHER, SIMON PERKINS, ASHLEY WALKER AND ERIK WOLFART : **Hypermedia Image Processing Reference,** Department of Artificial Intelligence ,University of Edinburgh, UK, 1994 *(http://www.cee.hw.ac.uk/hipr/html/filtops.html)*

[5] RAFAEL C. GONZALEZ, RICHARD E. WOODS: **Digital Image Processing** – Second Edition

[6] P. HELLIER, C. BARILLOT, E. MÉMIN, P. PÉREZ. **Medical image registration with robust multigrid techniques**. Proc. of the 2nd Int. Conf. on Medical Image Computing and Computer-Assisted Intervention, MICCAI, C. Taylor, A. Colchester (eds.), Springer Verlag, Lecture Notes in Computer Science, Volume 1679, pages 680-687, Septembre 1999.