Monomodal and Multimodal Registration using the ICP Algorithm

R. Khemakhem, O. Ben Sassi, A. BenHamida and A. Taleb-Ahmed

Abstract— **In this paper we present the principal approach of medical images registration. The registered images are assumed to be rigidly aligned using the Iterative Closest Point (ICP) algorithm. The tasks to be realized consists in making a monomodal registration intra-subjects based on two Magnetic Resonance Image, and a multimodal registration intra-subjects based on a Magnetic Resonance Image (MRI) and an ElectroEncephaloGraphy exam. The multimodal registration is preceded by the resolution of inverse problems in Electroencephalography (EEG) to make the reconstruction of the active sources. We have used for the multimodal registration the standardized LOw Resolution Electromagnetic Tomography-FOCal Underdetermined System Solver (sLORETA-FOCUSS) inverse problem method which given good results for neuronal activity reconstruction. So we have obtained good registration results.**

Index Terms—**EEG, MRI, ICP algorithm, Segmentation, Monomodal Registration, Multimodal Registration, sLORETA-FOCUSS.**

I. Introduction

Image registration is the process of determining the correspondence between all points in two images of the same scene or different scene [1]. It is possible to align the images manually, but that requires too much time and it is irreproducible. It is consequently desirable to automatic means of registration of the entire images.

The registration of two images allow for the combination of complementary information from both images. The goal of image registration is to establish the correspondence between two images and determine the geometric transformation that aligns one image with the other. Most of the fusion errors originate from poor data registration processes, which is essential for fusing multisource data.

Magnetic Resonance Imaging (MRI) and electroencephalography (EEG) are two complementary clinical aided tools for diagnosing as well as for exploring respectively the space and temporal scale of the cerebral activity. To localize the active sources in the brain, the first point is to solve the inverses problems. Then we make the registration of the obtained result on MRI images. The image registration consists to find the best geometric transformation by optimizing the function of similarity between two images. This function is considered the center of the registration because it defines the objective used to estimate the quality of registration between two images.

The registration procedure matches the skin surface, segmented from MRI, and a digitized description of the head performed with a 3D tracker during the EEG examination. With this automatic registration method the fusion of EEG localizations with MRI anatomical data gives highly significant information. For the monomodal and the multimodal case, the general approach consists in assuming global relationship between the intensities of the images.

So, to achieve the registration, one can use an EEG signal to detect high-frequency phenomena, like sleep spindles, inter ictal epileptic events and correlate the presence/absence of these phenomena with the MRI BOLD. By detecting the MRI voxels with high correlation, one can identify brain regions that are involved in the generation of the EEG phenomena under study.

Section 2 describes the principal of monomodal and multimodal registration. In section 3 we present the ICP algorithm for registration. Section 4 concerns the resolution of the inverses problems using the new method sLORETA-FOCUSS. Section 5 presents the obtained results of monomodal and multimodal registration. Finally we conclude in section 6.

II. Monomodal, Multimodal Registration

Many classes of registration tasks can be recognized based on the modalities that are involved. In monomodal applications [2], [3] the images are registered belong to the same modality, as opposed to multimodal registration tasks [4], [5], [6], where the images are registered stem from two different modalities [7]. Nevertheless, whatever the type of application, registration procedure generally follows the same principal presented in

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Fig. 1 and requires the definition of certain criteria according to [8], [9]. These criteria are:

1) Extraction of pertinent information: it is a preliminary step of pre-processing that allows guiding registration. These information, constructed from I_s (source image) and I_t (target image) using the functions F_s and F_t, are based on characteristics of image data.
   Various characteristics are exploited to drive image registration algorithms and they include:
   - Geometric methods: they consist in the extraction of the geometric feature, such as points, contours, or surfaces, manually or automatically.
   - Iconic methods: they present the low level information in the image such as pixel intensities, and pixel positions.
2) Transformation: The transformation used to register two images can be categorized according to the domain of transformation that can be global in which the transformation is applied to the entire image, or local in which different regions of the image have their own transformations defined. In both domains the transformations can be:
   - Rigid. An image coordinate transformation is called rigid, when only translations and rotations are allowed.
   - Affine. Transformations mapping parallel lines onto parallel lines.
   - Projective. Transformations mapping lines onto lines.
   - Elastic. Transformations mapping lines onto curves. This is the more general image transformation that can be considered.

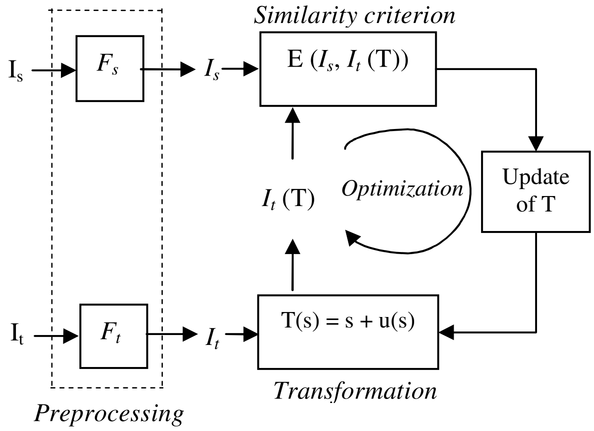

Fig. 1. General Principal of registration

3) Similarity criterion: image registration is based essentially on the similarity criterion measurement because it defines the objective criterion used to estimate registration quality between the homologous structures of images. Several criterions are usually employed and which are divided into two categories: feature-based techniques and intensity-based techniques.
4) Optimization: consists in finding the optimal transformation $\hat{T}$ which minimizes or maximizes the similarity criterion. Optimization task can be presented in the following way:

$$\hat{T} = \arg\min_{T \in \phi} E(I_s, I_t(T)) \qquad (1)$$

Φ: field of transformation

III. ICP Algorithm

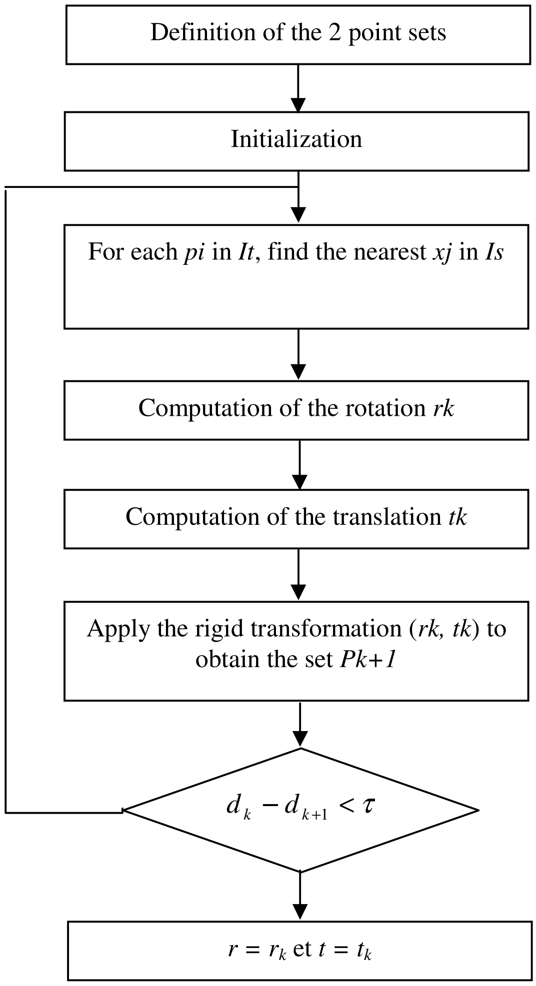

Fig. 2. Principal of the ICP algorithm

The ICP algorithm (Iterative Closest Point) was developed by Besl and McKay [10] and improved then by [11] and [12]. It is widely used to register several types of geometric data like point sets, triangle sets, implicit surfaces or parametric surfaces. However, it establishes point-to-point correspondence, so the data may need decomposition into point sets.

The algorithm calculates iteratively the registration. Given two sets P and X, it selects in each iteration step the closest points as correspondences and calculates the transformation (rotation 'r' and translation't') for minimizing the equation:

$$e(r,t) = \frac{1}{N}\sum_{i=1}^{N}\left\|(rp_i + t) - y_i\right\|^2 = \frac{1}{N}\sum_{i=1}^{N}\left\|(rp_i + t) - c(p_i)\right\|^2 \tag{2}$$

N: number of points in the data set.
'c': function associating each point pi with its corresponding in X. In this work, this function is based on the calculation of the Euclidean distance:

$$c(p_i) = x \big/ \min_{x\in X} d(p_i, x) \tag{3}$$

The iterative closest point algorithm can be stated as follows (Fig. 2):

1) Input: 2 point sets, $P = \{pi\}$ for $i=1\ldots Np$ (with Np the number of points in *It*) and $X = \{xi\}$ for $i=1\ldots Nx$, (with Nx the number of points in *Is*).
2) Initialization: k = 0, P_0 = P, r_0=I (identity) and t_0=(0,0,0).
3) Iteration k:
   - step1. Compute the closest points: Use the squared Euclidean distance to compute the set of Np closest points, $Y_k = \{y_{i,k}\}$, of $P_k = \{p_{i,k}\}$ defined as :

$$y_{i,k} = c(p_{i,k}) = x \big/ \min_{x\in X} d(p_{i,k}, x) \tag{4}$$

With

$$d(p_{i,k}, x) = \left\|p_{i,k} - x\right\|^2 \tag{5}$$

   - Step2. Compute the registration: Define the mean squared error of the couplings $\{p_{i,0}, y_{i,k}\}$ as a function of r_k and t_k.

$$e(r_k, t_k) = \frac{1}{Np}\sum_{i=1}^{Np}\left\|(r_k . p_{i,0} + t_k) - y_{i,k}\right\|^2 \tag{6}$$

Then compute the rigid transformation (rk, tk) such as:

$$e_k = \min_{r_k, t_k}(e(r_k, t_k)) \tag{7}$$

   - Step3. Apply the registration: Apply the best rigid transformation to obtain the set $P_{k+1} = \{p_{i,k+1}\}$ defined as:

$$p_{i,k+1} = r_k\, p_{i,0} + t_k \tag{8}$$

   - Step4. Iteration termination: Stop when the maximum number of iterations or a satisfactory convergence is reached. Set $r = r_k$ and $t = t_k$.
     A satisfactory convergence is obtained when:

$$d_k - d_{k+1} \prec \tau \tag{9}$$

4) Output: A transformation (r, t) that registers P and X.

IV. INVERSE PROBLEM

For the multimodal EEG/MRI registration, the first step is to solve the inverse problem [13] using the EEG signal to reconstruct the active zones in the brain.

Therefore, the inverse problem consists in estimating the various sources from the measurements of the potential on the scalp surface. The solution of inverse problem used in this case is the sLORETA-FOCUSS [14], that given the best reconstruction.

sLORETA-FOCUSS is a solution combining sLORETA (standardized Low Resolution Electromagnetic TomogrAphy) and FOCUSS (FOCal Underdetermined System Solver)[15] methods to improve the reconstruction in 3D of the neuronal activity in the brain. The sLORETA method [16] is a standard form of LORETA. It is a tomographic method for electric neuronal activity, where localization inference is based on images of standardized current density. FOCUSS is a recursive procedure. For each iteration, the matrix W is updated based on the current density estimate of the previous iteration "i".

The sLORETA-FOCUSS [17] method is summarized on the following steps:

- Calculation of the current density using sLORETA, then we obtain the $\hat{J}_{sLORETA}$
- Construction of the weighting matrix using the current density obtained by the sLORETA method

$$W_0 = diag(\hat{J}_{sLORETA}(i)) \tag{10}$$

- Calculation of the current density distribution using:

$$\hat{J}_i = W_i W_i^t K^t (K W_i W_i^t K^t)^+ V \tag{11}$$

Where W is the weighting matrix, K is the gain matrix, and J is the vector of density.

- Calculation of the iterative form of the weighting matrix W using:

$$W_i = PW_{i-1}\left[diag(\hat{J}_{i-1}(1), \ldots, \hat{J}_{i-1}(3M))\right] \tag{12}$$

- Calculation of the current density distribution of the sLORETA-FOCUSS method using the recursive expression of the FOCUSS method

- Repeat these steps until the solution $\hat{J}$ has no longer changes

The result suggests a sLORETA-LORETA method is able to reconstruct the 3-D source distribution in the brain.

V. RESULTS AND DISCUSSION

Like results, two modalities of image registration are used: the monomodal registration between two MRI images and multimodal registration between MRI images and the reconstruction results using an EEG signal [18] which were obtained by the Clinical Neurophysiology Service, CHRU Lille, FRANCE.

1) Monomodal registration MRI / MRI

To register two MR images applying ICP algorithm, we need firstly to extract the contour of the brain used for calculating the Euclidean distance.

The extraction of the contour is achieved through a set of morphological operations (Fig. 3) consisting first of a thresholding followed by dilation/erosion, and finally a detection of the contour of the obtained surface.

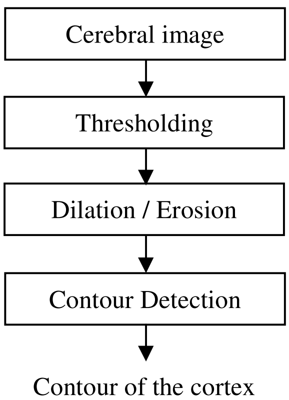

Fig. 3. Principal of cortex contour extraction

- Thresholding: This stage removes most of the background noise; usually the threshold is set to values between 30 and 40 for a 8-bit coded MRI sequence. This threshold relies only on the quality of the MRI acquisition and of the 16 to 8 bits transformation.
- Dilation / Erosion: Weak connections such as artefacts are removed by using a morphological opening; the number of iterations can be adapted according to the strength of these connections. The topology of the skin surface is preserved by applying the idempotence property.
- Contour detection: it can be achieved through classical contour based segmentation such as Prewitt operator, Sobel operator, Canny or Deriche edge detection.

In Fig. 4, we present the segmentation steps of the two MRI images.

Segmentation based registration methods attempt to find the best transformation that will align the contours of corresponding segmented structures onto each other. A wrong segmentation will influence the registration since the skin surface extraction is directly derived from this stage.

In Fig. 5, we present the result of monomodal registration between two MRI images before transformation (Fig. 5c) and after transformation (Fig. 5d) using ICP algorithm.

After simulation, we found the required optimal transformation among a set of transformation defining the field deformation of the image.

The optimal rotation angle is r =0 degree and the optimal vector translation is:

$$t = \begin{pmatrix} tx \\ ty \end{pmatrix} = \begin{pmatrix} 2 \\ 0 \end{pmatrix}$$

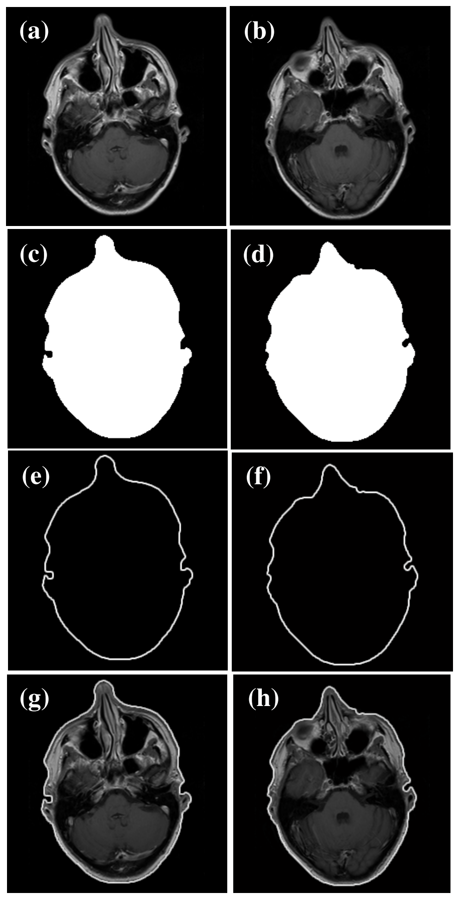

Fig. 4. Cortex contour extraction
(a) Source image; (b) Target image;
(c), (d)Thresholding and dilation / erosion;
(e), (f) Contour Detection;
(g), (h) Verification of the segmentation result by superposing the contour on the image

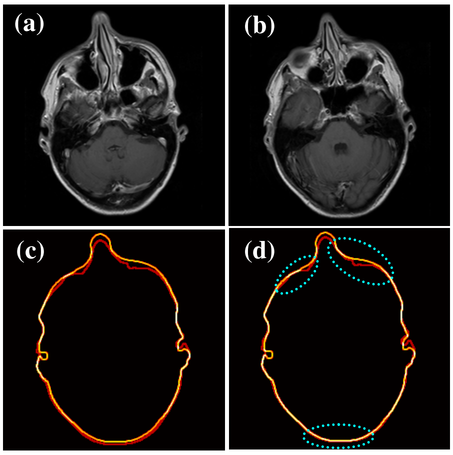

Fig. 5. Monomodal Image Registration

2) Multimodal registration MRI / EEG

The multimodal registration is giving by using the two modalities EEG and MRI.

The first step is to solve the inverse problem to reconstruct the active sources in the brain. The second step consists on the registration between reconstruction result and a standard MRI model.

We have used for this style of registration, the ICP algorithm; our results are presented in Fig. 6.

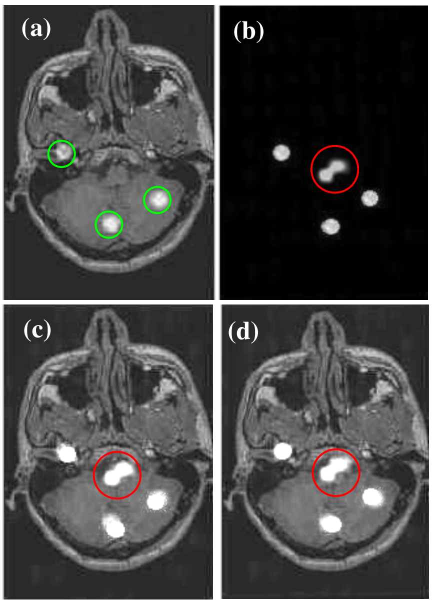

Fig. 6. Multimodal Image Registration

In Fig. 6 the red points indicate the reconstructed dipole using the sLORETA-FOCUSS inverse problem methods. The points marked in green refer to referenced points used for the registration phase.

Before the registration a statistical analysis was performed, for each subject. The registration stage is used between the reconstructed result using the sLORETA-FOCUSS inverse problems and the standard form of the MRI slices. Voxel property based registration methods operate directly on the image grey values. A similarity criterion is defined between the two images and the registration is operated by searching for the transformation that maximises the registration criterion.

The rotation angle is r =1 degree and the optimal vector translation is:

$$t = \begin{pmatrix} tx \\ ty \end{pmatrix} = \begin{pmatrix} 3 \\ 2 \end{pmatrix}$$

VI. CONCLUSION

Brain registration is a hybrid field, builded upon contributions from several disciplines, including, but not limited to, mathematics, computer science, anatomy, neuroscience, and imaging. In this paper we have presented a general strategy for monomodal and multimodal registration of the medical images using ICP algorithm. We have used for the multimodal registration the EEG signal, where the reconstruction of the active sources is given by the resolution of the sLORETA-FOCUSS method. As results, we have obtained a satisfactory registration.

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REFERENCES

[1] M. CHEN, T. KANADE, D. POMERLEAU, and J. SCHNEIDER. « 3-D Deformable Registration of Medical Images Using a Statistical Atlas ». report CMU-RI-TR-98-35, Robotics Institute, Carnegie Mellon University, December, 1998..

[2] J. Orchard, C. Greif, G.H. Golub, B. Bjornson, M.S. Atkins, «Simultaneous registration and activation detection for fMRI », IEEE Transactions on Medical Imaging, vol. 22, no° 11, Novembre 2003, p. 1427-1435.

[3] S. Periaswamy, H. Farid, « Medical image registration with partial data », Elsevier Science, Mars 2005.

[4] P.A Van den Elsen., J.B.A. Maintz, E.D. Pol, M.A. Viergever, «Automatic registration of CT and MR brain images using correlation of geometric features », IEEE Transactions on Medical Imaging, vol. 14, n° 2, Juin 1995, p. 384-396.

[5] J.F. Mangin, Frouin V., Bendriem B., « Non supervised 3D registration of PET and MRI data using chamfer matching », IEEE Transactions on Medical Imaging, 1993, p. 1262-1264.

[6] C. Barillot, Fusion de données et imagerie 3D en médecine, Habilitation à diriger des recherches, Université de Rennes 1, Septembre 1999.

[7] G. K. ROHDE, A. ALDROUBI et B. DAWANT. « The adaptative bases algorithm for intensitybased nonrigid image registration ». IEEE Transaction on Medical Imaging, vol.22, No.11, novembre 2003.

[8] Brown L.G., « A survey of image registration techniques', ACM computing surveys », Janvier 1992, p. 325-376.

[9] J. B. A. MAINTZ and M. A. VIERGEVER. “A survey on medical image registration”. Medical Image Analysis, vol. 2, pp. 1–36, 1998.

[10] Besl P.J., McKay N.D., « A method for registration of 3-D shapes », IEEE Transactions on pattern analysis and machine intelligence, vol.14, n°2, Feb.1992, p.239–256.

[11] Z. Zhang, «Iterative point matching for registration of free-form curves», rapport de recherche n° 1658, Mars 1992, INRIA.
[12] T. Jost, «Fast geometric matching for shape registration », Thèse de doctorat, Université de Neuchâtel, 2002.
[13] A. Tarantola, «Inverse Problem Theory and Methods for Model Parameter Estimation", Institut de Physique du Globe de Paris, Université de Paris 6, Paris, France, 2005
[14] R. Khemakhem, A. BenHamida, A. Taleb-Ahmed, P. Derambure. «New hybrid method for the 3D reconstruction of neuronal activity in the brain ». 15th International Conference on Systems, Signals and Image Processing June 25-28, 2008, Bratislava Slovakia.
[15] I. F. Gorodnitsky, J. S. George, and B. D. Rao, «Neuromagnetic source imaging with FOCUSS: A recursive weighted minimum norm algorithm» Electroenceph. Clin. Neurophysiol., vol. 95,1995, pp. 231–251.
[16] R.D. Pascual-Marqui. « Standardized low resolution brain electromagnetic tomography (sLORETA): technical details ». Methods & Findings in Experimental & Clinical Pharmacology 2002, 24D:5-12. Author's version.
[17] I.F. Gorodnitsky, J.S. George, and B.R. Rao, « Neurmagnetic source imaging with FOCUSS: a recursive weighted minimum norm algorithm». Electroenceph. Clin. Neurophysiol., vol. 95, pp. 231-251, 1995.
[18] B. ZITOVA, J. FLUSSER « Image registration methods: a survey », Image and Vision Computing 21(2003) 977-1000.

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