A hybrid automated algorithm for mammogram registration using mutual information

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Abstract—Mammographic image registration is an important step in the comparative analysis of mammograms. In this paper, we present an automatic algorithm for mammogram registration using mutual information. In the first phase, the algorithm is initialized by a rigid coarse registration to compensate the differences linked to the global movements of the breast during the two acquisitions. In the second phase, we combined between the multiresolution technique based on Gaussian pyramid and the progressive image subdivision strategy in order to find the non rigid global transformation of the registration process. In both phases, mutual information is used as similarity measure to take into account the variations between intensities of similar structures of the breast for different studies of mammograms. The performance of the suggested framework has been evaluated by aligning mammograms from the MIAS database. The obtained results are satisfactory for the different mammograms studied.

Index Terms—registration, mammograms, mutual information, Gaussian pyramid, progressive subdivision approach.

I. INTRODUCTION

The breast cancer is the most common disease in woman in the world [1]. The radiologists carry out a comparison of bilateral and temporal pairs of mammographies in order to detect the abnormal structures at breast tissues and to follow up the pathological evolution in time. On the other hand, the comparison of couples of mammographies is not a simple task to achieve. The variations in the acquisition conditions (different adjustments in the acquisition devices, the variations linked to the breast compression and the global movement of the breast during acquisition) the nature of mammography images which are projections of 3D structures in a 2D plan, differences due to an anomaly (bilateral pairs) as well as the deformable aspect of the breast along time (temporal couples) can introduce global deformations in these images as well as the local changes in the internal tissues of the breast for different acquisitions. These factors can engender spatial differences between similar structures of the breast producing such wrong diagnosis during the comparative analysis of mammograms. In order to compensate these differences, it’s essential to implement a registration algorithm witch determine the transformation that lines up corresponding mammograms in a same geometric spot.

The aim of this paper is to present a registration method of temporal and bilateral mammogram pairs. Since the time factor is important for clinical routines, a good registration method is considered as a compromise between the registration quality and the execution time of this process. The objective of this article is to try to satisfy this compromise. The quality of the registration method is carried out by the use of mutual information as a measurement of similarity to ensure an automation of the registration process and to take into consideration the potential changes at gray levels between similar structures of the breast. On the other side, the implementation of a progressive subdivision strategy of images into subimages allows to take into account the local and global deformations which can affect the breast. Concerning the calculating time, the implementation of an initial rigid registration compensating the distortions linked to the global movement of breast as well as the adoption of a multiresolution strategy allowed to reduce computation cost of registration process.

The rest of this paper is organised as follows: In the next section, we describe the approaches of mammograms registration. Next, we present the hierarchical algorithms of registration. Then, we discuss the adopted methodology in section 4 and the experimental results in section 5. Finally, we conclude this paper with the future research on the subject.

II. MAMMOGRAM REGISTRATION

In order to correlate the mammographies, some methods have been based on a rigid model of registration. Such approach is characterized by its speed due to the fact that the rigid transformations (of simple translations and rotations) described and it allows to compensate the differences linked to the global movement of the breast during the two acquisitions [2]. Nevertheless, local differences can be targeted at the internal tissues of the breast for different acquisitions. Therefore, some choices which are justified by a rigid registration to correspond mammographic images are not bound to be the most adopted to take into account the local deformations, of a non rigid nature, that can affect the breast for different
acquisitions. These methods can thus carry out a non-pertinent registration.

In order to describe the local changes which can affect the breast for different acquisitions, it proves to be the most appropriate to use a non rigid registration model. For that purpose, many non rigid registration approaches of mammography have been suggested [3, 4, 5].

Some approaches are based on the anatomic structures of the breast [6, 7, 8]. A major limit of these approaches is their dependence of the segmentation step especially that breasts tissues are compressible structures characterized by a lack of distinct morphologic primitives. In addition, these methods are less efficient regarding to the variability of the internal tissues of the breast over time and to the natural asymmetry of these tissues.

Nevertheless, other approaches have been based on the images intensity values. Some approaches present a simple physical model of breast defined by partial differential equations; others pose a problem of energy minimization on the breast area, with boundary conditions derived from a preliminary mapping of the breast contours [9]. However, these methods are iterative and costly in term of calculating time. So, in order to compensate for this issue, many simplifications have been introduced to these registration methods. Among others, the implementation of hierarchical algorithms [10] which are the most adapted for this kind of registration.

III. HIERARCHICAL ALGORITHMS OF REGISTRATION

A. Hierarchical image subdivision

This strategy consists in carrying out a progressive subdivision of images to be registered into more and more small sub-images which will be after locally and independently registered [11]. The calculation of the global non rigid transformation is assessed by interpolation of all local transformations.

The number of the sub-images to be matched increases from the coarsest level to the finest. This approach is a part of the hierarchical algorithms class of warp [10] where the size of the registered images is fixed and the number of sub-images increases from one level to another so increasing warp complexity at each level as illustrated in figure 1.

B. The multiresolution based on Gaussian pyramid

In order to accelerate the non-rigid registration algorithms, Some authors adopted a multiresolution strategy based on a Gaussian pyramid [12]. It consists in registered the images in a low level of resolution and propagating the parameters assessed from the registration in a higher level of resolution. The registration is restarted until the extent of an original level of resolution. This approach belongs to the class of hierarchical algorithms of data [10].

The number of images to be registered is fixed and their size (resolution) increases progressively going from one level to another until the finest level of the pyramid. So, increasing data quantity at each level until the original level of resolution. Its principle is illustrated in figure 2.

Despite these simplifications, the cost of non rigid registration algorithms still remains higher to insert them in the Computer Aided Detection (CAD) systems. Therefore, it’s interesting to combine in the same framework the hierarchies of data and warp to reduce simultaneously the deformation’ complexity and the data quantity at each level decreasing thus the computation cost of the global registration algorithm.

IV. METHODOLOGY

The most processes of mammograms registration use either a rigid or non rigid method in order to match couples of images as per the function to be optimized. On the other hand, this mode of thinking does not comply with reasoning of human experts who start from global vision level to a local level more precise. The adopted methodology in this paper is inspired from this perception mode. Basing on bilateral and temporal pairs of mammography, the methods of image registration described below, divided into rigid and non rigid methods, as well as hierarchical algorithms are mentioned in the previous section are used.
A. Rigid registration method based on mutual information

The rigid registration is described by rotation and translation. The registration parameters are recovered by optimizing a similarity criterion. The mutual information is retained to find the transformation parameters searched for. Contrary to the current methods basing on the measurement of image’s intensities, the mutual information basing on the quantity of information that contains the images. It is the most performing for mammographic image registration [13].

The calculation of the similarity criterion based on mutual information (MI) (1) for two images I, J involves the calculation of statistical measurement called entropy of images I and J (2), (3) in addition of the joint entropy (4) of I and J:

\[ MI(I, J) = H(I) + H(J) - H(I, J) \]  
(1)

\[ H(I) = -\sum_{i=1}^{N} P(I(i)) \log P(I(i)) \]  
(2)

\[ H(J) = -\sum_{j=1}^{N} P(J(j)) \log P(J(j)) \]  
(3)

\[ H(I, J) = -\sum_{i=1}^{N} \sum_{j=1}^{N} P(I(i), J(j)) \log P(I(i), J(j)) \]  
(4)

Where P(I) and P(J) are the marginal probability distributions of the intensity levels of images I and J respectively.

In order to find the optimum transformation T which align the two images I and J, all you have to do is to maximize the mutual information MI according to the following expression:

\[ T = \text{Arg max} (IM(I, t(J))) \]  
(5)

Where t = T, and IM(I, t(J)) is the mutual information of image I and the transformed image of the image J using parameters of the rigid transformation T.

Since the transformation researched is rigid, the mutual information is maximized here by an exhaustive research [14] allowing to guarantee the obtaining of an optimum solution.

B. Non rigid registration method based on TPS transformation (Thin Plat Spline)

Thin-Plat Spline is a basic radial function which has been suggested for the medical image registration by Bookstein [15]. The function \( f(x, y) \) describing the plate minimizes the following energy function:

\[ \int_{\mathbb{R}^2} \left( \frac{\partial f}{\partial x} \right)^2 + 2 \left( \frac{\partial f}{\partial y} \right)^2 + \frac{\partial^2 f}{\partial x^2} \right) dx dy \]  
(6)

Where \( f \) is the interpolation function. This function ensures that \( f(x_i, y_i) = P_i \) for all control points \( P_i \) and performs the interpolation for all the other values. The mapping function is as follows:

\[ f_i(x, y) = a_i x + b_i y + t_i + \sum_{i=1}^{n} w_i U([\overline{P_i} - (x_i, y_i)]) \]  
(7)

\[ f_j(x, y) = a_j x + b_j y + t_j + \sum_{i=1}^{n} w_i U([\overline{P_i} - (x_i, y_i)]) \]  
(8)

Where \( a_i, b_i, t_i, a_j, b_j, \) and \( w_i \) are deformation parameters, \( N \) is the number of point, \( \overline{P_i} \) is the \( i \) th control point, \( (x, y) \) is any point. \( U \) is the thin-plate surface equation, \( w_i \) is the weight of the function U defined as follows:

\[ U(r) = r^2 \log(r^2) \]  
(9)

C. Description of the presented Framework

The combination of different methods written in the previous sections allows to benefit from their advantages. The first stage consists of performing a global rigid registration based on the mutual information (as mentioned in section A). It allows to compensate the effect of the global movement of the breast and used as an initialization for a non-linear registration as close as possible to the hoped result.

In the second stage, the mammograms rigidly registered are planned each in a Gaussian pyramid. In the coarse level of the pyramid, only a rigid registration is necessary because the size of images to be matched is minimum. At the following level, the mammograms are subdivided into four sub-images of the same size and each one is aligned rigidly with its corresponding in the reference image using mutual information. This registration is made up of a coarsest level until a finest one and of a thin resolution until the original one.

For each level of the pyramid, a displacement vector made up of translations (moving in x and y) is generated for each pair of the matched sub-images. The set of these vectors are considered as control points which used with association of the method of Thin Plat Spline spatial transformation (as mentioned in section B) in order to find the global non rigid transformation [14]. The number of the corresponding sub images in the finest level of the pyramid is \( 4^N \), where \( N \) is the number of the applied resolution. So, using the Gaussian pyramid approach, the global size of images to be registered decreases progressively from one level to another until getting a minimum size in the coarse level of the pyramid as illustrated in figure 3.

Because of this, except the finest level of the pyramid, the size of the manipulated images is minimum compared with those of works based only on the hierarchical subdivision strategy [11] which are of fixed size for all levels.

Combining simultaneously the hierarchy of warp (illustrated in figure 1) and the one of data (illustrated in figure 2), the quantity of data decreases simultaneously with the complexity of warp which will enormously reduce the CPU time necessary for the execution of registration algorithm. In addition, the implementation of a global rigid registration at the start of non rigid algorithm contributes to an important reduction in the number of iterations necessary for the convergence of the algorithm which will decrease automatically the computing cost. This proves the usefulness of the presented hybrid algorithm in terms of calculating time.
V. EXPERIMENTAL RESULTS

We have already proved the effectiveness of the suggested framework in terms of calculating time (computation cost) in the previous section. In this section we are going to validate the registration accuracy of our algorithm.

Methods are implemented in Matlab under the platform Windows and have been tested on different mammograms pairs from the MIAS database [17]. This basis contains Medio Lateral Oblique (MLO) views of right and left breasts, which are used to assess the bilateral registration.

Concerning temporal registration, rigid deformations were introduced to the reference mammography in order to simulate global transformations linked to the changes in the breast’s position during different acquisitions.

The registration is performed for 4 levels of resolutions counting the original level with 64 sub-images to be rigidly registered in this level.

A. Qualitative Validation

Since our data are of the same modality, the image-subtraction technique for mammograms pairs before and after registration is kept to validate the robustness of the applied registration.

We present in figure 4 and 5 two examples of results of the suggested algorithm for a real bilateral couple and simulated temporal couple. After the first step of the algorithm, the applied rigid registration allowed to remove the most global differences between mammograms for the two studied cases. The second step of the algorithm led to local improvements.

Concerning temporal couples, global transformations of rigid nature have been introduced to the manipulated mammograms which does not reflect the whole real differences that can the breast suffer from with time. These real differences can be due to a pathologic evolution as well as to natural changes in the internal tissues of breast and can engender differences in intensities between similar structures of breast.

Because of this, it remains to assess the suggested algorithm effectiveness for real cases of temporal mammograms containing local deformations.

B. Quantitative validation

In order to prove the usefulness of the mutual information, we compared quantitatively our results with those obtained by an algorithm that supposes a relationship between mammograms to be compared. So, we are going to calculate some measures for temporal mammograms compared with those of works used the coefficient of correlation as a similarity measure [16]. The measurements used are CC, MSE and PSNR.

- The measurement CC (coefficient of correlation) is given by the following expression (10):

\[
CC = \frac{\sum m \sum n (C_{mn} - \bar{C})(S_{mn} - \bar{S})}{\sqrt{(\sum m \sum n (S_{mn} - \bar{S})^2)(\sum m \sum n (C_{mn} - \bar{C})^2)}}
\]  (10)
• The measurement MSE (Mean square error) is given by the following expression (11):

\[
\text{MSE} = \frac{1}{N} \sum_{i=1}^{n} \sum_{j=1}^{m} (S(i,j) - C(i,j))^2
\]  

(11)

• The measurement PSNR (peak signal to noise ratio) is given by the following expression:

\[
\text{PSNR} = 10 \log \frac{1}{\text{MSE}} \cdot 255^2
\]  

(12)

Results are illustrated in table I before and after registration.

According to table I, in both algorithms, we notice that the cross correlation (CC) take highest values after registration. Where compared between the two algorithms, we can see that our algorithm increase similarity between mammograms as well as the registration errors that considered less important which prove the precision of the applied registration approach by using the mutual information.

VI. CONCLUSION

The contribution of this article aims to develop an automatic method of mammograms registration and to avoid to fall within the dependence of the step of the extraction of control points from anatomic structures of breast. The time factor is taken into consideration. First, the implementation of a gross rigid registration allowed to initialize the research for the non rigid registration decreasing so the number of iterations which reduces computing cost. Then, the combination of a multisolution approach with the progressive subdivision technique (that allowed to take into account local and global deformations) decrease therefore the CPU time.

In order to avoid the effects of artifacts during the elastic interpolation, we are limited just to translations as rigid local transformations. Because of this, our results are not conclusive and can be again more precise in order to increase the reliability of the presented algorithm.

An interesting perspective of this work consists also in testing this approach for real cases of temporal pairs as well as more bilateral couples that contains more important differences and assessing the obtained results by experts in radiology.

Mammograms registration is not a goal in itself, the information resulting from registration is the first step for the analysis of bilateral and temporal pairs which will be our next research.

| TABLE I. RESULTS OF THE APPLIED ALGORITHM COMPARED WITH THOS OF REGISTRATION ALGORITHM USED THE CROSS CORRELATION [16] |
| Cross correlation based approach | Proposed approach |
| Before | After | Before | After |
| CC | 0.79 | 0.953 | 0.78 | 0.961 |
| MSE | 2729 | 635 | 2358 | 544 |
| PSNR | 31.70 | 46.28 | 33.16 | 47.83 |

REFERENCES


