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Temporal mammogram image registration using optimized curvilinear coordinates

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ABSTRACT

Registration of mammograms plays an important role in breast cancer computer-aided diagnosis systems. Radiologists usually compare mammogram images in order to detect abnormalities. The comparison of mammograms requires a registration between them. A temporal mammogram registration method is proposed in this paper. It is based on the curvilinear coordinates, which are utilized to cope both with global and local deformations in the breast area. Temporal mammogram pairs are used to validate the proposed method. After registration, the similarity between the mammograms is maximized, and the distance between manually defined landmarks is decreased. In addition, a thorough comparison with the state-of-the-art mammogram registration methods is performed to show its effectiveness.

1. Introduction

The goal of *image registration* is to find the optimal transformation function that aligns one image with another. In other words, the registration process should bring the coordinates of the current (template) mammogram to the coordinates of the previous one. Registration helps doctors analyze and visualize of mammograms. The comparison of mammograms requires a registration (alignment) method. Four breast mammogram comparisons are usually performed [19]:

- *Temporal analysis* is performed between mammograms for the same breast at different screening examinations.
- *Bilateral analysis* is performed between mammograms of the left and right breasts of the same woman.
- *Ipsilateral analysis* is performed between the craniocaudal (CC) and mediolateral oblique (MLO) views of the same breast.
- Analysis of breast images acquired from different *modalities* (e.g. X-ray with magnetic resonance imagining (MRI)).

A full review of medical image registration methods can be found in [18,28]. Few works have evaluated the performance of image registration methods using mammograms. In [8], an evaluation of four registration methods with MLO–MLO or CC–CC mammogram pairs was presented. The utilized methods were: nipple-based alignment, center of mass alignment, warping based on manually selected control points and mutual information-based (MI) registration method. The MI-based method yielded the best registration results, whereas, the control points-based method performed worst. Diez et al.

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[7] presented a quantitative evaluation of state-of-the-art intensity-based image registration methods applied to mammographic images. The study assessed the suitability of global rigid transformation and local deformable registration methods for mammographic image analysis. They showed that local deformations (multi-resolution B-Spline deformations) obtain the most accurate registration results. In [21], a comparison between affine, fluid and free-form deformation registration methods was shown. The study concluded that the affine method achieved the best registration results.

The main drawbacks of the existing mammogram registration methods are that they use either non-realistic global transformations or local deformable models. The global registration methods cannot properly cope with the local deformations; in turn, the local deformation models may yield unrealistic deformations.

In this paper, we propose a framework for temporal mammogram registration based on a transformation model derived from the breast anatomy, namely the *curvilinear coordinate system*. In curvilinear mapping, a coordinate pair (s, t) is assigned to each pixel in Cartesian coordinates, (x, y). The theoretical point of view of the proposed representation was inspired from the work proposed in [5] where a dimensionless polar coordinate system was used to generate a new representation for iris images. The construction of the curvilinear coordinates does not require any information about the internal structures of the breast. To construct the curvilinear coordinates, we use the breast boundary and a reference point located on it. Thus the resulted representation of a given mammogram is invariant to changes in the size, position and orientation of the internal structures of the breast (the internal structures do not play any role on the construction process). We utilized the curvilinear coordinates to cope both with global and local deformations in the breast area and compensate the deformations between the mammograms.

Fig. 1 shows a mammogram that has been forwardly transformed from the Cartesian coordinates to the curvilinear coordinates, and then it has been inversely transformed from the curvilinear coordinates to the Cartesian coordinates.

The use of curvilinear coordinates in mammogram registration enables us to build a registration approach based on a reasonable grid which mimics the anatomy of the breast, instead of using the Cartesian grid which is composed of vertical and horizontal lines. In addition, mammogram registration based on the curvilinear coordinates does not need determining control points nor use of a correspondence algorithm. The parameters of curvilinear coordinates may be optimized, as will be shown later, to find the best alignment between the reference and template images.

A preliminary work [22] presented the basic idea of the use of the curvilinear representation to register the mammograms. However, the current paper contains more contributions such as:

- We proposed an optimization procedure to find the optimal reference points of the curvilinear coordinates for both, the reference and the template mammograms (Section 3.2), whilst in [22] the location of the reference points were assumed at the middle of the breast boundary.
- In [22], the authors assumed that the segmentation of the breast boundary was given. In the current work, we integrate the segmentation procedure within the registration framework. Moreover, we discuss the effect of boundary segmentation on the accuracy of the proposed method (Section 4.3).
- We evaluate the proposed method with a private mammographic images database, containing realistic deformations between the mammograms; in contrast, few mammograms with artificial deformations were used in [22].
- A review and a discussion for the related mammogram registration methods are added in this paper (Section 2). Comparisons with some related works are also provided (Section 4.4).

The rest of this paper is organized as follows. Section 2 presents the related work. Section 3 explains the proposed registration framework as well as the dataset used in this work. Section 4 presents the experimental results. Section 5 presents the conclusion and some lines of future work.

2. Related work

In general, image registration methods can be divided into *feature-based* and *intensity-based* methods. However, with mammogram registration, more specific registration categories are existing such as *breast contour-based*, *anatomical structures-based* and *image representation-based* methods. Here, we discuss the related work of each category.

2.1. Feature-based registration methods

Feature-based methods depend on the features extracted from the mammograms. Control points are the most used features in registration of mammograms. Marias et al. [17] used a set of breast boundary points and internal points with thin plate spline to register a pair of temporal mammograms. They used a matching approach to detect the potential internal points by comparing the features of the local maximum and minimum points in the breast region in the reference and template mammograms. Hong et al. [11] also proposed a method to compare mammogram pairs. They extracted salient regions in a topological way. An integral invariant representation of shape, in combination with area and distance measures, were used to establish the correspondences between mammograms. Furthermore, Lionel et al. [31] proposed a curvilinear structure-based mammogram registration approach. In their method, they incorporated junctions of curvilinear structures as internal landmarks. The curvilinear structures describe connective tissue, blood vessels and mammary ducts, which are detected by an algorithm based on the monogenic signal. The junctions are extracted using a local energy-based method, which considers the orientation information provided by the monogenic signal.

Indeed, it is difficult to extract consistent features from the mammograms because the appearance of the breast region dramatically depends on the strength of the compression which was applied to the breast using the compression paddles; therefore, few distinct landmarks can be determined. The