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Computer-aided diagnosis of mammographic masses using local geometric constraint image retrieval

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ABSTRACT

Computer-Aided Diagnosis of masses in mammograms is an important indicator of breast cancer. The use of retrieval systems in breast examination is gradually increasing. Hence, in mammographic mass retrieval, the method of exploiting the vocabulary tree framework and the inverted file has been proven to have high accuracy and excellent scalability. However, it only considered the features in each image as a visual word and ignored the spatial configurations of features, which greatly affects the retrieval performance. To overcome this drawback, we adopt the geometric verification method in mammographic mass retrieval. First, we obtain corresponding match features based on the vocabulary tree framework and the inverted file. Then, we grasp local similarity characteristics of deformations within the local regions by constructing the circle regions of corresponding pairs. Meanwhile, we quarter the circle to express the geometric relationship of local matches in the area and strictly generate the spatial encoding. Additionally, we rotate local matches in the area to control the strictness of geometric constraints. Finally, we verify geometric consistency to filter the false matches.

The experimental results demonstrate that our method could significantly improve the retrieval accuracy with low computational cost.

1. Introduction

Breast cancer is the second leading cause of cancer-related deaths among women (exceeded only by lung cancer) [1]. While it cannot be fully prevented, early detection allows for the best chances of effective treatment before it spreads to other parts of the body. Currently, several imaging techniques for breast examination are available such as mammography, ultrasonography, and MRI, with mammography being the most effective and widely accepted method [2].

The major indicators in imaging of breast cancer are masses and micro-calcifications. It is commonly believed that the detection of mammographic masses is a more challenging task than that of micro-calcifications, as mammographic masses have large variations in size, margin and shape [3,4]. Meanwhile, even experienced radiologists make different judgements in the interpretation of mammograms [5]. Since radiologists may experience exhaustion due to the large numbers of mammograms screened manually, they may overlook vital clues in studying scans [6].

CAD methods provided substantive help in the decision-making process of radiologists. The purpose of these methods is to reduce the time spent in the diagnosis of lesions and to reduce false diagnosis [7]. Most of these methods extract features from mass lesions

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and train classifiers to achieve discrimination between masses and normal tissues [7–9].

Recently, content-based image retrieval (CBIR) approaches have increasingly gained attention for mammograms and other medical images [10–13]. The purpose of such an approach aims to offer decision-making capabilities in the context of similarly retrieved images that belong to cases stored in a reference database. CBIR-based CAD methods first prompt radiologists to label a region of interest (ROI) in the query case, compare it with the database ROIs extracted from previously diagnosed cases, and finally return the most similar cases along with the likelihood of a mass in the query case [10]. These approaches have several advantages over classifier-based methods. First, as long as similar ROIs exist in the database, these methods can detect "unusual" masses. They then provide more clinical evidence to help diagnose.

The existing CAD methods have demonstrated the great value of CBIR technology in the retrieval and analysis of medical images. However, the vast majority lack scalability. They do not apply the indexing scheme but rather require a comparison of the query image with a considerable number of database images, resulting in a linear relationship between the retrieval time and the total number of databases, which poses a great challenge in terms of processing time. Therefore, most mammogram retrieval methods are currently tested on at most one thousand mammographic ROIs. Obviously, lack of scalability can hinder the use of these valuable medical images. Meanwhile, the lack of scalability limits the diagnostic accuracy of CAD applications. The larger the database, the more likely it is to find related cases and the easier it is to assist radiologists in making correct diagnoses [14,15]. Therefore, the scalable CBIR technology has become one of the most pressing issues in medical imaging [16]. To solve this problem, Jiang et al. [17] attempts to tackle the large-scale medical image analysis problem for the first time. They exploit the vocabulary tree framework and the inverted file in mammographic mass retrieval. There is a high level of accuracy and excellent scalability due to the low spatial-temporal cost of vocabulary tree. Despite the output from performing a query on the inverted file, the features in each image are considered as visual words and have ignored the spatial configurations of features. The process also suffers from visual word ambiguity and quantization error. Therefore, the discrimination ability of the local features is reduced. These unavoidable disadvantages greatly affect the retrieval performance, since different features may be quantized to the same visual word, causing many false local matches between images [18].

In this paper, we apply the novel geometric verification method in mammographic mass retrieval. Inspired by Jiang et al. [17], we proceed to research the large-scale medical image analysis problem and consequently make further improvements. First, we obtain corresponding match features between query and database ROIs based on the vocabulary tree framework and the inverted file. Next, we grasp the local similarity characteristic of deformations in the local regions by constructing the circle regions of corresponding pairs. Meanwhile, we quarter the circle to express the geometric relationship of local matches in the area and strictly generate the spatial encoding. Additionally, we rotate the quartered circle to control the strictness of the geometric constraints. Finally, we verify geometric consistency to filter the false matches. Through our geometric verification method, the false matches can be removed effectively and efficiently, resulting in better accuracy. Preliminary results have been published in the proceedings of SPIE [19]. Compared with this method, this paper has undergone significant changes. First, it is substantially extended to provide more details about our method as well as the techniques on which it is based. Then, the reason that our method has succeeded in mammographic mass retrieval is introduced in detail. Finally, the experiments are considerably improved by adding two compared methods as well as additional details about the discussion of the parameters.

This study offers three contributions. First, in order to realize large-scale medical image retrieval, it adopts the geometric verification method based on the vocabulary tree framework and the inverted file, which capture the spatial relationship among local features in large-scale medical image retrieval. Second, we denote the discrepancy of the spatial configurations between matched features in general images and matched features in mammograms. Finally, we design an effective geometric verification method, which is suitable for mammographic mass retrieval.

The remainder of this paper is organized as follows. Section 2 reviews some related work on general CBIR methods and CBIR-based mammographic CAD. Section 3 illustrates the proposed method in detail. Experimental results are illustrated in Section 4. Finally, we summarize the conclusions in Section 5.

2. Related work

2.1. General CBIR methods

The adopted visual features play an important role in the retrieval precision and efficiency of the CBIR method. Visual features can describe the various attributes of the whole image or local image area, commonly referred to as global features and local features. Frequently exploited attributes include colour, texture, shape, and spatial relationships. Among great numbers of features, SIFT [20] is widely applied due to its wonderful robustness and discriminative power. The SIFT high-dimensional local feature is typically quantized for fast retrieval. Hence, CBIR methods based on the Bag-of-Words (BoW) model have received extensive attention [18,21–23]. The contribution of the BoW model [24] is that it achieves scalability for large-scale image retrieval by quantizing local features to visual words. The BoW model not only compacts image representation by quantizing high-dimensional local features to low-dimensional global features, but it also achieves rapid retrieval by indexing images with inverted file structure. However, the quantified visual words based on the BoW model may reduce the discriminative power of the local features. Different features may quantize to the same visual word and features with the same semantics may also be recognized as different visual words, which would cause many false local matches between images and consequently affect retrieval performance. To solve this problem, most researchers observe that the BoW model does not capture geometric relationships between matched features, and further focuses on filtering the false matches by encoding spatial context of local features into image representation. Hoang et al. [25] describe the