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Automated classification of maxillofacial cysts in cone beam CT images using contourlet transformation and Spherical Harmonics

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ABSTRACT

Background and objective: Accurate detection of maxillofacial cysts is an essential step for diagnosis, monitoring and planning therapeutic intervention. Cysts can be of various sizes and shapes and existing detection methods lead to poor results. Customizing automatic detection systems to gain sufficient accuracy in clinical practice is highly challenging. For this purpose, integrating the engineering knowledge in efficient feature extraction is essential.
Methods: This paper presents a novel framework for maxillofacial cysts detection. A hybrid methodology based on surface and texture information is introduced. The proposed approach consists of three main steps as follows: At first, each cystic lesion is segmented with high accuracy. Then, in the second and third steps, feature extraction and classification are performed. Contourlet and SPHARM coefficients are utilized as texture and shape features which are fed into the classifier. Two different classifiers are used in this study, i.e. support vector machine and sparse discriminant analysis. Generally SPHARM coefficients are estimated by the iterative residual fitting (IRF) algorithm which is based on stepwise regression method. In order to improve the accuracy of IRF estimation, a method based on extra orthogonalization is employed to reduce linear dependency. We have utilized a ground-truth dataset consisting of cone beam CT images of 96 patients, belonging to three maxillofacial cyst categories: radicular cyst, dentigerous cyst and keratocystic odontogenic tumor.
Results: Using orthogonalized SPHARM, residual sum of squares is decreased which leads to a more accurate estimation. Analysis of the results based on statistical measures such as specificity, sensitivity, positive predictive value and negative predictive value is reported. The classification rate of 96.48% is achieved using sparse discriminant analysis and orthogonalized SPHARM features. Classification accuracy at least improved by 8.94% with respect to conventional features.
Conclusions: This study demonstrated that our proposed methodology can improve the computer assisted diagnosis (CAD) performance by incorporating more discriminative features. Using orthogonalized SPHARM is promising in computerized cyst detection and may have a significant impact in future CAD systems.

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1. Introduction

The accurate detection of lesions and tumors is an important step in computer-aided diagnosis systems. This step is usually performed by a radiologist; however, manual detection becomes tedious in the presence of small sized lesions and is time consuming due to the large amount of data to be analyzed. Hence, developing an automatic or semi-automatic method can save radiologists' time. Automatic detection of jaw cysts is a challenging task and machine learning based methodologies can simplify this task.

CBCT (cone beam CT) is a rapidly advancing area of imaging specifically designed for maxillofacial region and can provide three dimensional images of hard and soft tissue structures with lower dose of radiation [1,2]. This is an important aspect since sensitive tissues and organs are located in head and face. In evaluating cysts or benign tumors, OPGs[1] may not fully record the dimension and location of the lesion. Multi-planar sections (axial, coronal, and sagittal planes) and 3D reconstruction are required in examining cysts or tumors. In several studies, accuracy of CBCT images in diagnosing jaw cysts is evaluated [3–8]. Many researchers reported that the accuracy of CBCT imaging is comparable to conventional CT with no significant statistical difference [3,5,8]. However, like other imaging technologies, surgical biopsy and histopathological evaluation are needed for further accurate differential diagnosis of some lesions [4]. Thus, it can be concluded that CBCT is a reliable tool for preoperative radiological assessment of cyst and tumors when compared with conventional CT.

Periapical or radicular cyst is the most common type of maxillofacial cysts. Radicular cysts account for more than 50% of all inflammatory cysts and they are the main reason of chronic swelling in mandible [9]. The second prevalent cyst is dentigerous cyst which is associated with the crown of an unerupted tooth. Keratocystic odontogenic tumor is the third most common odontogenic cyst which is of great importance due to the high possibility of recurring [9]. To the best of our knowledge, there are very few researches performed for maxillofacial cysts detection. Flores et al. [10] combined graph-based random walks segmentation with machine learning-based boosted classifiers in order to diagnose dental periapical lesions. In [11], an algorithm is developed to identify dental cyst using morphologic descriptors of the shape, margin and area at an early stage. Then, a neural network is trained to diagnose and measure severity of cysts with high classification accuracy in dental X-rays. A combination of support vector machine and bagging with logistic regression was proposed by Frydenlunda [12] to classify four types of developmental odontogenic cysts in digital micrographs. Landini et al. [13] used a semi-automated algorithm to segment histopathological images of odontogenic keratocysts and radicular cysts into theoretical cell regions. They obtained various morphometric features which proved to be successful in the classification of radicular cysts and odontogenic keratocysts.

Designing an algorithm for maxillofacial cysts detection is a challenging task due to several reasons. First, cysts can be of various sizes and shapes and conventional detection methods will lead to poor results. Hence, information such as shape and texture should be utilized to gain more accurate result. Second, examination of 2D slices is a time consuming task for a radiologist. Thus, an effective computer aided diagnosis procedure would reduce the workload and the costs of multiple expert diagnostic opinions. This goal is the main motivation of this article.

According to dental radiologists, accurate and fast classification of maxillofacial cysts is clinically very important. To our knowledge, there is no existing automatic system that can sufficiently address this problem. This is the clinical impact of this research. To this aim, engineering integrations is essential and this is the main novelty of this paper. Due to the capability of shape and texture features in studying the effects of various diseases, we have proposed a novel hybrid framework for cystic lesions detection. To this aim, a combination of SPHARM and contourlet features is employed. SPHARM is one of the most widely used methods in studying anatomical structures such as brain and liver [14,15]. SPHARM allows us to study 3D shape variations between different diseases and contourlet features provide texture information for physicians in finalizing their diagnosis process. Moreover, an adaptive algorithm is utilized for increasing the accuracy of SPHARM features. The idea of performing an extra orthogonalization procedure to reduce the bias of IRF estimation was also proposed by Wang in [16]. By orthogonalizing Spherical Harmonics, residual sum of squares will decrease which leads to a more accurate estimation. The practical efficiency of proposed framework is proven experimentally using different classifiers such as support vector machine and sparse discriminant analysis.

The rest of this paper is organized as follows. In Section 2, we first describe the dataset and method used for segmentation of cystic lesions in CBCT images. Afterwards, we briefly introduce feature extraction methods, i.e. Spherical Harmonics and contourlet. In Section 3, residual sum of squares in orthogonalized SPHARM is compared to conventional SPHARM representation. Statistical measures for methods validation are described in Section 4. Then, in Section 5, experimental results are reported. Finally, in Sections 6 and 7 discussion and conclusion are presented, respectively.

2. Methods

In this section, we introduce different components of the proposed framework. The proposed methodology uses shape features to describe overall geometrical characteristics of the cystic region and texture features to represent image characteristics inside them. When we were collaborating with various radiologists, we observed that they consider geometrical features (i.e., the shape of cystic region) and they perform a comparative reading between different types of cysts. While texture information is critical resource for disease classification, it is not sufficient to screen for the presence of cystic lesions, and the overall geometrical shape characteristics of cystic lesions give significant aid in classification performance. In this section, we will cover the details about the proposed method for automatic segmentation of cysts, con-

[1] Orthopantomogram.