Computational Characterization of Thyroid Tissue in the Radon Domain

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Abstract

This paper investigates a novel computational approach to thyroid tissue characterization in ultrasound images. It is based on the hypothesis that tissues in thyroid ultrasound images may be differentiated by directionality patterns. These patterns may not be always distinguishable by the human eye because of the dominant image noise. The encoding of the directional patterns in the thyroid ultrasound images is realized by means of Radon Transform features. A representative set of ultrasound images, acquired from 66 patients was constructed to perform experiments that test the validity of the initial hypothesis. Supervised classification experiments showed that the proposed approach is capable of discriminating normal and nodular thyroid tissues, whereas nodular tissues can be further characterized as of high or low malignancy risk.

1. Introduction

Thyroid nodules are lumps within the thyroid gland, with a considerable clinical importance because of the risk of malignancy, involving occurrences of papillary, follicular, medullary and anaplastic carcinomas. The prevalence of thyroid nodules increases with age, extending to more than 50% of the world's population, whereas 50% of people with solitary nodules detected by experienced physicians have additional nodules detected when examined further by ultrasonography [1].

Thyroid ultrasonography is a non-invasive diagnostic test, which provides immediate information on the structure and the characteristics of thyroid nodules. It combines low cost, short acquisition time, absence of ionizing radiations and sensitivity in ascertaining the size and number of thyroid nodules. However, ultrasound (US) images contain echo perturbations and speckle noise, which could make the diagnostic task harder, whereas the subjectivity involved in their interpretation can be regarded as their major drawback. A system that would be able to interpret US images based on explicit features could contribute to the objectification of medical diagnosis as it could provide the experts with a second opinion, and could lead to a consequent reduction in misdiagnosis rates.

Only a few studies have focused on developing computational approaches to thyroid tissue characterization by US image analysis. Image intensity information has been used for the identification of thyroid Hashimoto disease [2], for the detection of nodular thyroid lesions [3], and for thyroid tumor classification [4]. Textural image information encoded by means of co-occurrence matrix features [5] have been utilized for identification of chronic inflammations of thyroid gland [6] and for the discrimination between normal and pathologic tissues [7].

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In this paper, we investigate computational characterization of thyroid tissue by supervised classification of directionality patterns in thyroid ultrasound images. It is based on the hypothesis that tissues in thyroid ultrasound images may be differentiated by directionality patterns whereas the initial motive is based on radiologists' observations. However, differentiations of image directionality patterns are associated with differentiations in the interaction of US radiation with tissues. Radon domain [8] features have been considered to encode the directionality patterns. These features involve integral operations enabling noise-robust pattern representation in the inherently noisy US images.

The rest of this paper is organized in three sections. Section 2 describes the Radon Transform and the features encoding the image directionality patterns. The results of the application of the proposed approach on real thyroid US images are apposed in Section 3, and the conclusions of this study are summarized in Section 4.

2. Radon Domain Features

Let (x, y) be the cartesian coordinates of a point in a 2D image, and $u(x, y)$ the image intensity. The 2D Radon Transform denoted as $R_u(\rho, \theta)$ is given by

$$R_u(\rho,\theta) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} u(x,y)\delta(\rho - x\cos\theta - y\sin\theta)dxdy \quad (1)$$

where ρ is the perpendicular distance of a line from the origin and θ is the angle formed by the distance vector.

A feature vector representing a directionality pattern of an image region can be defined as follows:

$$[R_u(\rho_1,\theta_1),...,R_u(\rho_1,\theta_n),R_u(\rho_2,\theta_2)...,R_u(\rho_2,\theta_n),...,R_u(\rho_l,\theta_1),...,R_u(\rho_l,\theta_n)] \quad (2)$$

where l and n are the number of Radon projections and angles respectively, considered for each image region, provided that the origin of the region is its center.

3. Results

A special purpose software suite in Microsoft Visual C++ implementing the proposed algorithm was developed and executed on a 3.2 GHz Intel Pentium IV workstation. Thyroid ultrasound examinations were performed on 66 patients using a digital US system HDI 3000 ATL with a 5-12 MHz linear transducer. The acquired digital images had a resolution of 256×256 pixels and 256 gray-level depth.

3.1 Classification of nodular and normal thyroid tissues

Two regions of 32×32 pixels were extracted from each US image, one including normal thyroid tissue and one including nodular tissue (Fig. 1). This process provided a balanced dataset containing 132 tissue samples for training and testing. Feature vectors were extracted from each region with the use of Radon Transform, as described in Section 3. The optimal values for l and n (see Section 2) were experimentally determined as 4 and 3 respectively, resulting in feature vectors comprised of 12 components.

Comparative experiments are performed by applying the Radon-based approach and the coocurrence-based approach on the same dataset. The non-parametric k-Nearest Neighbor classifier, with k=5, was used in order to facilitate direct comparisons. Classification was performed by means of the leave one out method [9]. The overall classification accuracy obtained by the application of the proposed Radon-based approach was 84.1%, whereas the classification accuracy obtained by the application of the coocurrence-based approach was

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71.2%. It should be noted that both approaches outperformed mean intensity on the same dataset, as the classification accuracy obtained with the latter was 67.4%. These results support our initial hypothesis that tissues in thyroid ultrasound images may be differentiated by directionality patterns, which can be encode by features in the Radon domain.

The classification performance of the proposed Radon-based approach was further optimized by the use of the SVM classifier. The value of the tolerance parameter C and the kernel type [10] providing the maximum classification accuracy, were experimentally determined as C=40 and the polynomial kernel respectively. The leave one out method was also used in this case. The overall classification accuracy obtained by the application of the proposed Radon-based approach was 90.9%.

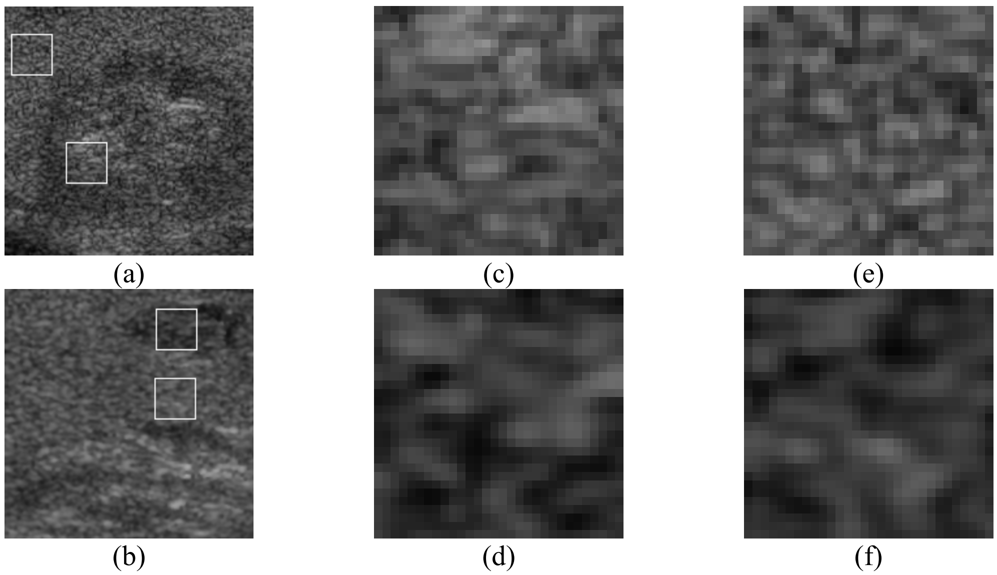

Figure 1. (a-b) thyroid ultrasound images, (c-d) nodular regions, (e-f) normal thyroid regions.

3.2 Differentiation of nodular tissues with respect to their malignancy risk

Three expert physicians characterized each of the 66 nodules used in the experiments of the previous subsection, as high-risk or low-risk, following the classification of [11]. The corresponding 66 regions of 32×32 pixels, which included nodular tissue, provided a dataset containing 35 samples of low-risk tissues and 31 samples of high-risk tissues, for training and testing. As the optimal values for k and l were experimentally determined as 5 and 4 respectively, the feature vectors extracted from each region with the use of Radon Transform were comprised of 20 components.

Comparative experiments were performed in similar fashion with the previous subsection, with the use of the k-Nearest Neighbor classifier (k=5). The leave one out method was also used in this case. These experiments resulted in classification accuracies of 86.3% and 74.2% for the proposed Radon-based approach, and the coocurrence-based approach respectively. The classification accuracy obtained by the application of mean intensity is 75.6%, more than 10% lower than the one obtained by the proposed approach.

The classification performance of the proposed Radon-based approach was further optimized by the use of the SVM classifier. The value of the tolerance parameter C and the kernel type [10] providing the maximum classification accuracy, were experimentally determined as C=100 and the polynomial kernel respectively. The leave one out method was also used in this case. The overall classification accuracy obtained by the application of the proposed Radon-based approach was 89.4%.

4. Conclusion

We have proposed a novel computational approach to thyroid tissue characterization in ultrasound images. It is based on the hypothesis that tissues in thyroid ultrasound images may be differentiated by directionality patterns. The encoding of the directional patterns is realized by means of Radon Transform. The proposed approach was experimentally evaluated and compared with a co-ocurrence-based approach on a representative set of thyroid ultrasound images. The results of this experimental study support our initial hypothesis, demonstrating that the proposed approach achieves higher classification accuracy than the co-ocurrence-based approach, in the classification of nodular and normal thyroid tissues, as well as in the differentiation between types of thyroid nodules with respect to their malignancy risk.

Feature perspectives of this work include utilization of feature vectors extracted with the use of Radon Transform for: 1) the development of a computer-aided thyroid nodule characterization system, 2) applications on various clinical domains including breast, prostate and cardiac ultrasound.

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