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Hierarchical classification of normal, fatty and heterogeneous liver diseases from ultrasound images using serial and parallel feature fusion

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This study presents a computer-aided diagnostic system for hierarchical classification of normal, fatty, and heterogeneous liver ultrasound images using feature fusion techniques. Both spatial and transform domain based features are used in the classification, since they have positive effects on the classification accuracy. After extracting gray level co-occurrence matrix and completed local binary pattern features as spatial domain features and a number of statistical features of 2-D wavelet packet transform sub-images and 2-D Gabor filter banks transformed images as transform domain features, particle swarm optimization algorithm is used to select dominant features of the parallel and serial fused feature spaces. Classification is performed in two steps: First, focal livers are classified from the diffused ones and second, normal livers are distinguished from the fatty ones. For the used database, the maximum classification accuracy of 100% and 98.86% is achieved by serial and parallel feature fusion modes, respectively, using leave-one-out cross validation (LOOCV) method and support vector machine (SVM) classifier.

1. Introduction

Liver which is the body's largest and most complicated gland weighs almost 1500 gr. It performs many essential functions related to digestion, metabolism, immunity, and storage of nutrients in the body. These functions make the liver a vital organ; so, its related diseases has attracted great attention since a long time ago [1].

In general, liver diseases can be categorized into two groups: focal and diffused. The former are the ones, in which abnormalities are concentrated within a small area in the liver such as tumor or cyst; but, the latter are the ones which distribute all over the liver tissue and affect the whole liver, such as fatty liver [1–3]. The liver normally contains some amounts of fat on its exterior surface, which shields the organ from harmful effects of toxic substances that can enter from the lungs during the intestinal blood filtration process. However, when this fat deposit constitutes more than 5-10% of the liver's weight, it is termed as a fatty liver condition.

There are three main methods of diagnosing fatty liver:

1. Blood test: including tests of liver enzymes, may help your doctor make a diagnosis. *This does not confirm a diagnosis of fatty liver. Further analysis will look for the cause of inflammation.*

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2. Imaging: Imaging procedures used to diagnose fatty liver disease include ultrasound, computerized tomography (CT) scan and magnetic resonance imaging (MRI).
3. Biopsy: A liver biopsy is a procedure to remove a small sample of liver tissue for laboratory testing. *This is the only way to know for certain if one have fatty liver but it is invasive and expensive*.

Although biopsy is the "gold standard" for diagnosing liver diseases, ultrasonography is mostly preferred because it is non-invasive (no needles or injections), cost-effective, widely available and has nonradioactive nature.

Because ultrasound B-mode images have a granular structure that is texture-like, the analysis of ultrasound images is similar to texture classification.

Nowadays, medical images such as ultrasonography, CT, and MRI are of great importance in the diagnosis of diseases. Since diagnosis based on these images is performed by clinicians, it has some limitations. Clinicians' analysis is subjective and depends on their experiment and precision. As a consequence, we need a quantitative, reliable, and error-free method for diagnosing liver diseases based on ultrasound images. Therefore, computer-aided diagnostic (CAD) systems can help clinicians in detecting and increasing the accuracy.

Improvement in computer technology and pattern recognition has led to the broad usage of CAD in medical fields. In a CAD system, defining a set of meaningful features is regarded as the most important section. Feature extraction can be obtained by considering the spatial relationship between the pixels which defined over small neighborhoods such as using grey level co-occurrence matrix (GLCM), gray level different statistics (GLDS), gray level run-length matrix (GLRLM), statistical feature matrix (SFM), local binary pattern (LBP), etc. Another method for extracting meaningful features can be done in the transform domain of an image, i.e. over diverse scales using multi-resolution schemes like discrete wavelet transform (DWT), wavelet packet transform (WPT), Gabor wavelet transform (GWT), etc. Most of the experiments have demonstrated that texture descriptors in transform domain are more useful and logical in the sense that these descriptors process images in a multi-scale way, like the human visual system (HVS) [4]. However, spatial domain analysis is of less computational complexity than feature extraction in transform domain.

Automatic classification of liver diseases from ultrasound images has been an important topic for researchers. Different aspects of a CAD system can change the result of the system; so, various combinations of de-noising, segmentation, feature extraction, and classification methods give various results, which generate main challenge for researchers in terms of finding the best tool. A similar database is used in [5,6] for classifying fatty, normal, and heterogeneous liver images with an automatic diagnosis; one with WPT to achieve the classification accuracy of 97.9% and the other with CLBP features to obtain 98.67% as classification accuracy. In [7] spatial-domain features including GLRLM, GLCM, first order statistics (FOS), fractal features (FF) and law's texture energy measures (TEM) by SVM classifier achieved the accuracy of 79.77%. In [8], the classification accuracy of 82.5% was obtained using GLCM and GLDS as spatial features. In another research [9], the multi-resolution features including DWT and WPT were applied and the classification accuracy of 93.54% was achieved. Minhas et al. [10] chose ROIs automatically and WPT features and got 95.4% accuracy by SVM classifier. Singh et al. [11] used information fusion by features including GLCM, GLDS, FOS, TEM, SFM, Fourier power spectrum (FPS), and FF to achieve the 95% accuracy. In [12], after extracting GLCM, multi-resolution fractal feature vectors and multi-resolution energy feature vectors, feature fusion was used to obtain 95.05% accuracy by K-nearest neighbor (KNN). In our previous work [13], feature fusion without using selection algorithms was proposed for distinguishing normal and fatty livers. It can be found that using spatial-domain features alone could not always lead to finding a good result; if we fuse spatial-domain features with the transform domain ones, the system accuracy can be improved.

There are mainly three types of fusion strategies, namely information fusion (low-level fusion), feature fusion (intermediate-level fusion), and decision fusion (high-level fusion). Information fusion combines a number of sources of raw data to produce new raw data which is expected to be more informative than the original ones [14]. When there are multiple feature sets, the fusion of all sets is a new feature set; and the technique is called feature fusion [12,15–17]. The last scheme of fusion involves a set of classifiers to provide a better and unbiased result that is decision fusion [18]. In some cases, both feature and decision fusions are used in a system [16].

Researches have shown that feature fusion has an important role in a CAD system and it can improve the system performance [12,15–17]. Feature fusion involves feature extraction and combination in a way that removes redundant and irrelevant features. Finally, the result of feature fusion has the most effective and least-dimensional features that can surely improve the classification accuracy for a given problem domain.

Feature fusion consists of three main steps [16]: feature extraction, feature selection, and feature combination.

This paper includes feature fusion techniques for classifying heterogeneous, fatty, and normal livers from ultrasound images. We specify the distinction between feature combination, one-level feature fusion and two-level feature fusion and also explain the concepts of serial and parallel feature fusion modes. The feature spaces include GLCM, CLBP, and multi-resolution feature vectors. In the one-level feature fusion, selection is achieved among the features of the combined feature vector. The two-level feature fusion consists of two steps of selection and combination: selection in individual feature spaces and selection through fusion of the selected features. Accordingly, we will have the most discriminative features for classification. These two methods are examined for both serial and parallel fusion modes.

Besides the description of feature fusion method, hierarchical classification is used as follows. In the first step, the focal and diffused livers are discriminated. Then, in the second step, fatty and normal livers are classified. All the experimental results indicate that the classification accuracy is increased significantly in comparison to the similar works and the dimension of the feature vectors is reduced largely under both serial and parallel feature fusion modes which can efficiently decrease the processing time. Hierarchical classification has