Ultrasound-based Classification of Fatty Liver Disease: A Review

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Abstract. Hepatic steatosis synonymous with fatty liver is a disease that results from excess fat in the liver. It's normal to have small amounts of fat in the liver, but too much can drag into a health issue. It is such a disease, which may lead to loss of human life, if not cured at an early stage. To detect such a disease highly precise and reliable technique is required such as ultrasound imaging. Different CAD frameworks have been proposed, to categorize the images as normal and fatty liver ultrasound images. Classifying the images with the assistance of the CAD systems developed till date is not found to be up to the mark. The sensitivity and accuracy measurements values still need improvement. Although much research has been carried out in this area, it is the subject of great significance due to increasing prevalence of fatty liver across the globe. In therapeutic imaging and diagnostic radiology, CAD has ended up a standout amongst the most important research topic. It introduces the pattern recognition software that analyse suspicious features on the image and help the radiologists to solve the problem. Over the past years, booming research has been done on classifying liver ultrasound images. This paper presents the recent trends in Ultrasound-based classification of various liver diseases through Computer Aided Diagnosis systems and the current challenges and future directions to improve the diagnostic accuracy.

1. Introduction

Ultrasound is a widely used imaging modality for many clinical applications like abdominal imaging, fetus analysis, liver diagnosis, echocardiography etc. This imaging modality is generally preferred over the other modalities such as CT and MRI scans as the equipment/apparatus used for ultrasound imaging is small and inexpensive as compared to the others. CT scans uses Radiations in the form of X-rays, thus categorizing it in the list of least preferred imaging modality. MRI scans are time consuming and expensive, further procedural difficulties during the MRI scans, sometimes forces patients to prefer ultrasounds over MRI scans. Each and every part of the body consists of different
types of cells and tissues, the fundamental element of life. Liver is one of the major organs in the body which plays a vital role in metabolism, bile production, synthesis of proteins, excretion process, control of glycogen storage, dissolution of red blood cells and also helps in maintaining the quality and volume of blood by purifying toxic products from the blood. Basically, the human body yields two types of harmful products i.e. bilirubin (produced due to the breakdown of old blood cells) and ammonia (produced due to the breakdown of proteins). Therefore, Liver helps in filtering internal harmful products as well as external sources like drugs, alcohol etc. Any problem with the liver may affect the whole body and results into a liver disease [2]. Fatty liver known as hepatic steatosis is kind of disease which happens due to the excess fat accumulation in the liver. The prevalence of fatty liver amongst adults in India is 24% [3]. This is one of the ailments that ought to be recognized and cured at the preliminary stage so as to cure a person. During the last few decades, ample research has been done in the field of Computer Aided Diagnosis (CAD) systems [4-7]. But still it is observed that the present CAD systems are not 100% accurate and reliable in providing the information about the fatty liver disease. [8].

The different segments of the present article are as per the following: Section 2 provides the description about liver diseases, ultrasound imaging and CAD. Section 3 gives an overview of published studies for fatty liver diagnosis. Section 4 provides scope for future work in the related area and conclusions are given in section 5.

2. Liver Disease and Tissue Characterization

2.1. Liver

Liver is one of the important organs in the human body; any disease related to liver may affect the functioning of liver. The following are the reasons that may lead to liver disease:

a. Infection in the liver
b. Use of drugs
c. Insulin resistance
d. Excessive use of alcohol

All the reasons listed above may lead to liver failure. [9].

2.2. Fatty Liver Disease (FLD)

Fatty liver disease is among the diseases that affect a large number of people around the world [10]. The fat content increases in the liver cells in this case. [11] Fatty Liver, also termed as Steatosis is the most challenging disease during diagnosis in terms of accuracy. As per the medical terminology, the types of fatty liver diseases those exist are: i) Alcoholic Steatosis, ii) Non-Alcoholic Steatosis. In 1980, the Non-Alcoholic Fatty Liver Disease was cited first time [12]. Excess Triglycerides in the liver may lead to such disease [13-14]. As per the reports it affects 15-24 percent of the population in the world [15]. The major reason behind the fatty liver disease is overuse of alcohol and only 10% cases are comprised of metabolic imbalances. [16]. In the absence of prompt diagnosis and care the fatty liver disease may result in liver failure and liver cirrhosis. Hence detection of fatty liver disease at early stage is important. Fig. 1.1 depicts the difference in liver ultrasound images.
In medical imaging, the Early diagnosis of FLD is considered as a very essential task, because with the help of proper treatment, disease incurred damage can frequently be reduced. Presently, a variety of methods is used to analyze FLD and these methods are classified into two types: FLD invasive techniques and non-invasive techniques [13, 18]. However, one of the invasive techniques to diagnose a fatty liver is Liver biopsy [19-20]. Since Liver biopsy detects FLD more accurately but patients have also suffered from pain and discomfort due to this invasive technique [21]. Many other non-invasive diagnostic techniques for FLD are being used like Computed Tomography, Functional Magnetic Resonance Imaging but among all ultrasound is most well-known image modality for FLD diagnosis. It is an economical technique and furthermore has high affectability. These diagnosis methods are briefly explained in the following paragraphs with summary of their advantages and limitations. Different types of causes and diagnosis techniques are shown in Figure 1.2.

**Figure 1.1** (a) Normal liver of the human body identified by the clean inferior pattern. (b) Fatty liver of the human body appear brighter and smoother.

**Figure 1.2** Causes and diagnosis of FLD.
2.3 Ultrasound Imaging

Ultrasounds are the sound waves with high frequency from 20 kHz to 10 GHz and travel in a medium as pressure waves. In medical applications, ultrasound ranges from 1MHz to 30MHz. Ultrasound (US) is a generally utilized imaging methodology to provides images in investigations of various human organ like embryo, joints, muscles, heart, blood cells, stomach and many more [22]. This technique provides less pain to the patients, is less expensive in nature, non-invasive, ray free and worldwide available. US method is used for a heavy estimation, liver image classification and the diagnosis of FLD [23-24]. Radiologist studies the liver ultrasound images on the basis of echogenicity. If the echogenicity is uniform all across the image the image is termed as normal image and if there is a variation in echogenicity in a liver ultrasound image, the same is termed as fatty liver [25]. The parameters like sensitivity and specificity of US needs improvement, when distinguishing fat build-up of more than 33%, the recorded sensitivities ranges from 60-94% and the specificities ranges from 75-100% [26-27]. The ultrasound imaging results are dependent on time-gain settings of the machine and operator thus leads to failure in identification of fatty and non-fatty liver images. For the optimum results and greater precision, manual procedures have been replaced with Computer Aided Diagnosis (CAD) system.

The most preferred imaging modality is the ultrasound imaging for the diagnosis of Fatty liver disease. [28].

2.4 Computer Aided Diagnosis System

Computer aided diagnosis (CAD) is a technique used to interpret the medical images. Applications of CAD systems enhance the performance of radiologists and hence improve the diagnosis results. CAD systems are computationally fast, have high accuracy and reliable as compared to the manual procedures in diagnosis of disease during classification of liver images. The basic aim of Computer aided diagnosis is to enhance the right diagnosis of a disease with the reduction in false negative rate. Various steps involved in computer aided diagnosis systems are Image pre-processing, segmentation, detection and classification. During pre-processing of ultrasound images, noise is reduced from the images for the better textural analysis of ultrasound images. Features like colour, brightness, size, shape etc. are usually extracted. A continuing texture in an image indicates a set of its features that are consistent, steadily changing or roughly regular [29]. The major aim of an ideal CAD system is to select unique features by using feature extraction models as mentioned in Table 1:

| Ref No. | Feature Extraction Model                          | Introduced By           |
|---------|--------------------------------------------------|-------------------------|
| [30]    | Spatial Gray-Level Co-occurrence Matrices (SGLCM) | Haralick                |
| [31]    | Fourier Power Spectrum (FPS)                     | Lendaris and Stanley    |
| [32]    | Gray Level Difference Statistics (GLDS)          | Weszka and Dyer         |

Finally, classifier like Bayesian classifier [33], Neural-Network Based Classifier [34], Support Vector Machine (SVM) classifier [35] categorizes fatty and non-fatty liver images.
3. Review of published CAD studies for fatty liver diagnosis

A comprehensive study of available literature is carried out, to review the research work already done in the related area. During the last few decades, the researchers are working hard to propose various models for categorizing the liver ultrasound images. The proposed classification models result in the texture feature extraction and feature selection techniques.

Singh et al. [11] categorizes the fatty and normal liver images at 95 percent accuracy by using feature selection techniques like Pearson’s Correlation Coefficient (PCC) and Linear Discriminative Analysis (LDA). The researchers selected 35 texture features, out of which 7 features. A new method was proposed by the researchers using a linear classifier.

Ribeiro et al. [36] categorizes the fatty liver images after considering the three feature models where 35 ultrasound images were used for evaluation purposes. In the classification of liver images, Probabilistic Neural Network (PNN) and K-Nearest Neighbour (KNN) classifiers are used.

Li et al. [37] considered dataset of 95 ultrasound images for categorization of liver images. By using SVM classifier the best features were extracted and the accuracy in case of normal liver is achieved as 84%.

Ribeiro et al. [21] categorizes the fatty liver images at an accuracy of 95% by using Quantitative Tissue Characterization Technique (QTCT). The authors selected distinct features and used the Naïve Bayer classifier to achieve sensitivity of 100%.

Singh et al. [38] considered 30 ultrasound images with ROI size 30×30 pixels. To study the proposed model, 5 texture models are used and the best features are extracted to obtain the accuracy equals to 92% after using fisher's linear discriminative (FLD) analysis.

Mukherjee et al. [39] considered the dataset of 100 ultrasound images and Self-Organizing Map (SOM) is used as classifier to obtain the profile plots. Liver images are categorized with the spatial patterns. With the use of “Maxp” and “Uni”, statistical texture analysis provided the desired results.

The literature survey [8, 41-43] clearly summarizes the literature review. The summary is as depicted in Table 2.

| Ref. No | Year | Source | Ultrasound Images Used | Image Size in pixels | Feature Extraction | Feature Selection | Classifier | Accuracy Rate |
|---------|------|--------|------------------------|----------------------|-------------------|------------------|------------|---------------|
| [39]    | 2007 | Chittaranjan National Cancer Institute, Kolkata | Normal: 76, Fatty: 24 | NA | SGLDM | Student's t test | Neural Network | NA |
| [4]     | 2008 | Ultrasonic imaging | 42 × 42 | 256×256 | GWT | NA | FFNN and | 94% |
| Reference | Year | Institution | Patients | Size (px) | Techniques | Classifier | Accuracy |
|-----------|------|-------------|----------|----------|------------|------------|----------|
| [35]      | 2008 | Municipal hospital | 25/68    | 767 x 572 | GLCM, NFLSD, NGTDM and NFFGR | Statistical SVM | 97%      |
| [21]      | 2009 | US Modality in a hospital | 10/10 | NA | RF and Speckle image. | NA | Naive Bayes 95% |
| [40]      | 2012 | Multan Institute of Nuclear and Radiologists | 39/30 | 560 x 450 | WPT & DWT | NA | SVM, ν-LSVC 95% |
| [36]      | 2012 | By radiologist in a hospital | 42/58 | 1024 x 1024 | GLCM, GLRLM, HOS based features, DWT. | NA | RBPNN, k-NN, Naive Bayes 93.30% |
| [38]      | 2012 | DDC, Patiala & PGIMER Chandigarh | 15/15 | 640 x 480 | SFM, TEM, SGLCM, FPS | FDR | Bayesian classifier 92% |
| [11]      | 2014 | DDC, Patiala & PGIMER Chandigarh | 90/90 | 640 x 480 | GLDS, FOS, FPS, SGLCM, SFM, TEM | FDR AND PCC | Information fusion-based classifier 95% |
| [46]      | 2016 | University of Malaya Medical Centre, Malaysia | 50/50 | 1024 x 1024 | GIST descriptor models | ROC, Student’s t-test, Bhattacharyya distance, Wilcoxon signed-rank test | AdaBoost classifier, Decision tree, Discriminant classifier, Naive Bayes, Probabilistic Neural Network, Support Vector Machine, K-nearest neighbor 98% |
| [47]      | 2017 | Taba Imaging Center, Iran | 28/47 | 768 x 1024 | GLCM and Wavelet Packet Transform (WPT) | NA | SVM 94.91% |
| [48]      | 2018 | Asian Institute of Gastroenterology, Hyderabad, India | 196 | NA | Curvelet transform and SVD | NA | Cubic kernel SVM and K-Nearest Neighbor 96.90% |
4. Future research directions

Based on the literature reviewed, following gaps and challenges have been identified:

Due to the presence of speckle, the quality of ultrasound images is degraded as it masks the fine details of tissues. Speckle may contain some important information, but it significantly reduces the image quality and causes problems in identifying fine details in images. From the literature surveyed it has been found that most of the speckle suppression filters perform well in homogenous areas but they lack near the edges either by leaving the speckle near the edges or they blur the edges while filtering. The majority of the methods accessible in the literature are not ready to protect edges and some fine details in the images. Along these lines, it is critical to suppress this speckle before any application.

Most of the available studies on liver tissue characterization are based on texture analysis, which are highly dependent on the control settings of ultrasound machine. Radiologists usually vary the time gain compensation; ultrasound frequency of probe and amplifier gain to get better display and information from the area of interest. These settings and changes are very subjective in nature, which makes ultrasound tissue characterization, observer and machine dependent [44]. Therefore, there is a need of method for liver characterization, which is independent of grey level of image and hence independent of ultrasound machine settings.

Visual criteria for differentiating the liver images are subjective in nature. Diagnosis of FLD depends largely on the operator’s ability to study texture features such as homogeneity, echogenicity (brightness) details in the ultrasound images, and later concluding with pathological findings. However, in case of marginal details of echogenicity through visual interpretation of ultrasound images is extensively argued among skilled radiologists. From the literature reviewed, it has been found that visual examination can yield diagnostic accuracy around 72%, which is less [45]. This augments the need for development of objective methods that are based upon quantitative analysis of texture patterns in classification of liver.
5. Conclusion

Ultrasound imaging is the most well-known technique on the grounds as it is non-ionizing, compact and real-time imaging technique. Fatty liver disease (steatosis) is a profoundly predominant disease among all the liver ailments in India. Researchers are working hard in the last few decades for liver classification through ultrasound imaging. But still there is a scope in terms of enhancement in accuracy and sensitivity of the obtained results. Categorization of liver ultrasound images is still a challenging task in manual procedures as the perceptual assessment of ultrasound images. Diagnosis of fatty liver disease is abstract and is not accurate in some cases. The more exact techniques are computationally costly, while the simpler to process strategies are not all that precise.

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