Using Short-Time Fourier Transform to Ultrasound Signals for Fatty Liver Detection

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Abstract—Currently, Fatty Liver Disease (FLD) is a serious disease that damages people’s health. Ultrasound imaging can assist in clinical screening and examinations of FLD. Note that fatty infiltration results in acoustic attenuation, which is hard to reflect by conventional Fourier Transform. In this study we applied the Short Time Fourier Transform (STFT) as an alternative method to evaluate the degree of fatty liver by ultrasound. The experimental results demonstrated that STFT can successfully describe the frequency change caused by attenuation effect, behaving well in detecting the stage of FLD. In the future, STFT may be combined with ultrasound scanners to implement real-time estimation of attenuation effect for FLD evaluation.

Index Terms—ultrasound, short time Fourier transform, fatty liver

I. INTRODUCTION

Fatty Liver Disease (FLD) occurs in 15% of the general population, and it has a prevalence of 75% among obese persons [1]. FLD is the cause of chronic liver injury, which will lead to fibrosis and cirrhosis [2]. So it is important to diagnose the FLD for most potential patients. Liver biopsy is the clinical method for detecting and assessing FLD. However, the biopsy program is invasive, and it may cause some different complications, such as internal hemorrhage. Furthermore, the sample volume is limited so it can not reflect the status of the whole liver accurately. Particularly, FLD is a chronic process of accumulation of fats, therefore patients who do not have the obvious clinical symptoms usually have no intention to go through a liver biopsy. For these reasons, non-invasive techniques should be taken into consideration to diagnose FLD. Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and ultrasonography (US) are the most used noninvasive techniques. Among these, US is the most important tool for evaluating FLD because it is inexpensive and real-time. The Ultrasound B-mode image shows brighter gray levels which can give physicians basic information to judge the status of FLD. It means that the ultrasound imaging is highly subjective and depends on the user experiences [3]. Therefore some objective methods of analysis are needed. Generally speaking, some objective approaches, such as texture analysis and Quantitative Ultrasound (QUS) techniques, have been widely applied in FLD detection [3], [4]. In QUS based imaging many parameters are estimated by using frequency or time domain based approaches, such as sound speed, backscatter coefficient and attenuation coefficient [5]. Attenuation coefficient is one of the parameters which can help us estimate FLD, because fatty infiltration increases the acoustic attenuation. Note that attenuation results in the downshift in ultrasound frequency [6]. If using a general Fourier transform to analyze the change in frequency, the temporal resolution of spectrum may be limited. In this study, we tried to use Short-Time Fourier Transform (STFT) as a method to evaluate the change in signal frequency to classify the stage of FLD by ultrasound. STFT may be a suitable choice as it can be used in vivo and real-time [7]. To the best of our knowledge, no any literature about using STFT for fatty liver detection was found.

II. MATERIALS AND METHODS

In this section, the collection of clinical liver data and data analysis are presented.

A. Clinical Data Collection

We recruited 25 volunteers to participate in the experiments. Pregnant women and patients who have habits of drinking alcohol and clinical symptoms related to liver diseases were excluded [8]. Prior to the experiments, the participants were asked to fast for eight hours and agreed to sign an informed consent form. During the experiments, a radiologist used a Terason ultrasound scanner to scan the participants’ right livers. The applied probe was a wideband linear array with 128 elements and a center frequency of 3.5MHz.

B. B-Mode Imaging

This programming was implemented using MATLAB software (Version 7.0.1, The MathWorks, Inc., MA, USA). At first, each scan line was demodulated using the Hilbert transform to construct the envelope image. The
Hilbert transform was implemented by using the ‘hilbert’ function in Matlab [9]. The envelope image was then compressed by logarithmic calculation to display the B-mode image in a fan-shape according to the geometry of the used curve probe (dynamic range = 40dB).

C. Scoring System for Fatty Liver

Given that the objective of this study is to explore the STFT for detecting FLD, not to use STFT statistics for accurately identifying the stage of fatty liver. The patients we recruited also did not have any clinical symptoms associated with liver diseases. For these reasons, invasive liver biopsy was not performed. The alternative method of staging FLD we adopted is a sonographic scoring system based on sonographic features, which is a well-accepted diagnostic protocol used for clinical detection of fatty infiltration of the liver. A gastroenterologist examined the ultrasound images to assign a score (1 = normal, 2 = mild, 3 = moderate, 4 = severe) for each patient.

D. Applying STFT and Estimating the Slope

In each image data, STFT was used to calculate the signal frequency as a function of time for each scan line. Subsequently, all data obtained from each scan line were used to establish the curve of -6 dB bandwidth ($\Delta f$) decrease. Finally, we compared the values of $\Delta f$ corresponding to different fatty scores. When STFT was performed there are some parameters could be changed.

- **L**: The length of data for analysis. We chose an appropriate length to process the data by observing the B-mode image. Usually, the data of parenchyma above the diaphragm will be chosen.
- **WL**: This was defined as the window length of STFT.
- **NFFT**: The number of FFT sample points.
- **H**: The window overlaps ratio parameter which was set as one eighth of WL.

Therefore it was necessary to find a best combination of these parameters. Meanwhile the calculation’s precision must be taken into consideration. Finally, the value of $\Delta f$ were used as the indication of fatty liver severity. At last we built the fit curve for the relationship between the four mean $\Delta f$ and liver scores. The (1) was selected to fit the data.

$$y = y_0 + \frac{a}{1 + e^{-(x-x_0)/b}}$$ (1)

All the parameters in (1) can be estimated. Once we get a $\Delta f$ of a new FLD patient whose fatty liver score is unknown, we can estimate the score through (1).

III. RESULTS AND DISCUSSION

A. B-Mode Images of Different Fatty Liver Score

Fig. 1(a) shows a typical B-mode image of a normal liver, while that in Fig. 1(b)-Fig. 1(d) are of livers with FLD at scores 2-4, respectively. As we can see the outline of the diaphragm is very clear because in the normal liver, echo level of the parenchyma is homogeneous. At a score = 2, vessel wall can be found in somewhere, but the echo brightness of the liver has a little increase. With the score increasing from 3 to 4, the attenuation of ultrasound through the liver becomes more and more notable so that the outline of diaphragm is gradually disappeared.

However, we can’t distinguish the severity from Fig. 1(b) to Fig. 1(d) accurately because it is difficult to find the differences between them.

B. Spectrum Images

When STFT was performed to the RF data of the four B-mode images, we got the corresponding spectrum images. As shown in Fig. 2, the vertical axis represents frequency up to 6 MHZ, the horizontal axis shows positive time toward the right, and the colors represent the most important acoustic peaks for a given time frame, with orange representing the highest energies, then in decreasing order of importance, yellow, green and blue, with the energy becoming less and less. From Fig. 2(a)-Fig. 2(d) we can find the center frequency is around 3 MHZ, and with time increasing, the bandwidth become narrower and narrower. And the part of yellow is faded, which indicate that the energy of ultrasound is attenuating.

Nevertheless, it is hardly to know which attenuation is most significant among Fig. 1(a)-Fig. 1(b).
C. Fitting Images

Now the frequency change need be quantified, so the Fig. 3(a)-Fig. 3(d) show the fitting procedure for the bandwidth narrowing course in Fig. 2(a)-Fig. 2(b).

Fig. 3(a) has two part which represent +6db and -6db bandwidth’s attenuation around the center frequency respectively, as well as Fig. 3(b)-Fig. 3(d). Then we can get the \( \Delta f \). The sample (a)-(d)’s \( \Delta f \) = 18.69%, 21.64%, 31.66%, 41.08%, respectively. According to the four \( \Delta f \), it is obviously that the higher fatty liver score have the more attenuation in frequency.

Now, if we want to detect the fatty liver by \( \Delta f \), a value for reference is needed. So we decide to use each mean \( \Delta f \) of the four fatty liver score group as reference value. If a patient’s \( \Delta f \) approximates the mean \( \Delta f \) of score 4, then he is most likely to suffer from severe fatty liver.

![Figure 3. Typical frequency change fitting course images at different scores of FLD: (a) score = 1, (b) score = 2, (c) score = 3, (d) score = 4.](image)

D. Relationship between Mean \( \Delta f \) and Liver Score

When the parameters are set as the Table I the relationship between mean \( \Delta f \) and score is most significant. As shown in Fig. 4, the slope is the biggest of all parameter combinations. In this condition, the slope is equal to 0.6373.

![Figure 4. Ultrasound frequency change as a function of fatty score. With increasing the degree of fatty infiltration, the frequency decreases accordingly.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>401 to 1100</td>
</tr>
<tr>
<td>WL</td>
<td>16</td>
</tr>
<tr>
<td>NFFT</td>
<td>1024</td>
</tr>
</tbody>
</table>

As mentioned above, all the parameters in (1) can be estimated. We finally got the (2).

\[
y = 21.15 + \frac{17.04}{1+e^{-(x-2.70/0.46)}}
\]  

According to Fig. 4, the curve has a rapidly increase when the fatty liver score comes from 2 to 3.

So we pick the mid-value of score 2 and score 3’s mean \( \Delta f \), which is equal to 26.65 as a threshold.

Once people’s \( \Delta f \) is bigger than the threshold, it means that he have the potential of fatty liver disease deteriorating.

IV. CONCLUSION

In this paper, the proposed method based on STFT was tested on total 25 samples’ liver data. The quantified frequency change parameter \( \Delta f \) correlates well with the severity of fatty liver. In the future, we could implement real-time analysis on attenuation-induced frequency change by STFT for the detection of FLD.

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REFERENCES

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