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

Chaojun Shou and Xiaoyu Chen
School of information and Electronic Engineering, Zhejiang Gongshang University, Hangzhou, China
Email: shouchaojun@163.com, xychen@zjgsu.edu.cn

Hao-Li Liu and Po-Hsiang Tsui
Department of Electrical Engineering, Chang-Gung University, Taoyuan, Taiwan
Email: {haoliliu, tsuiph}@mail.cgu.edu.tw

***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.

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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

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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 (Δf) decrease. Finally, we compared the values of Δf 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 need be taken into consideration. Finally, the value of Δf were used as the indication of fatty liver severity. At last we built the fit curve for the relationship between the four mean Δf and liver scores. The (1) was selected to fit the data.

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

All the parameters in (1) can be estimated. Once we get a Δf 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.

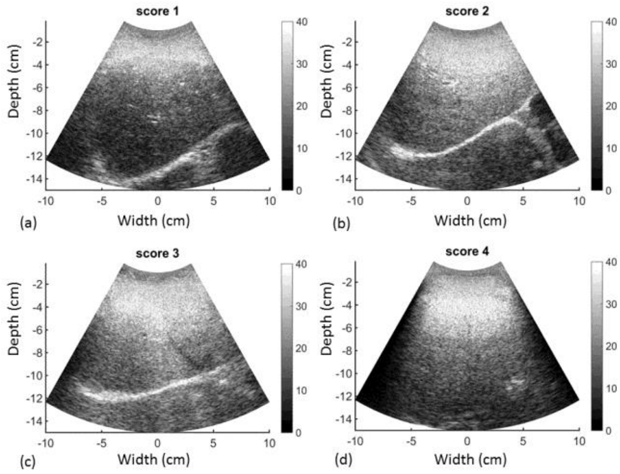

Figure 1. Typical B-mode images at different scores of FLD: (a) score = 1, (b) score = 2, (c) score = 3, and (d) score = 4.

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 6MHZ, 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 3MHZ, 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).

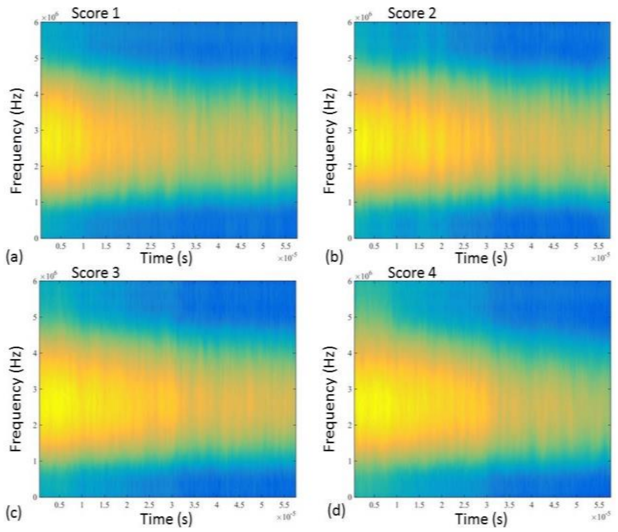

Figure 2. Typical amplitude spectrogram images at different scores of FLD: (a) score = 1, (b) score = 2, (c) score = 3, (4) score = 4.

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 Δf. The sample (a)-(d)'s Δf = 18.69%, 21.64%, 31.66%, 41.08%, respectively. According to the four Δf, 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 Δf, a value for reference is needed. So we decide to use each mean Δf of the four fatty liver score group as reference value. If a patient's Δf approximates the mean Δf of score 4, then he is most likely to suffer from severe fatty liver.

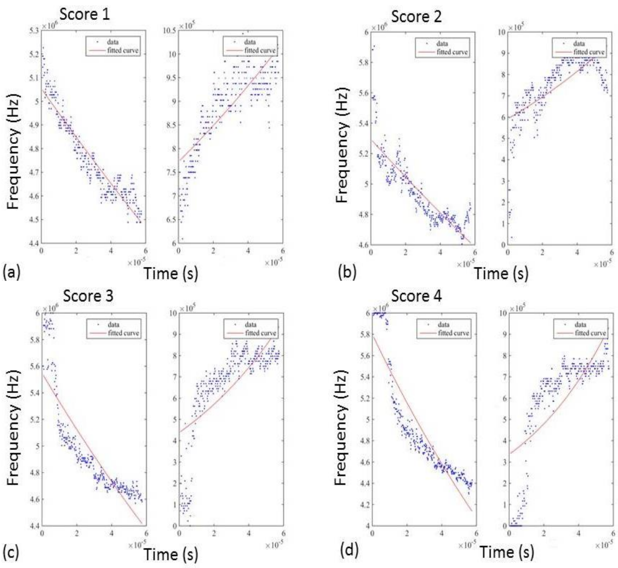

Figure 3. Typical frequency change fitting course images at different scores of FLD: (a) score = 1, (b) score = 2, (c) score = 3, (d) score = 4.

D. Relationship between Mean Δf and Liver Score

When the parameters are set as the Table I the relationship between mean Δf 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.

TABLE I. PARAMETER SETTING IN THE ALGORITHM OF STFT

Parameter	Value
L	401 to 1100
WL	16
NFFT	1024

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

$$y = 21.15 + \frac{17.04}{1+e^{-(x-2.70/0.46)}} \quad (2)$$

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 Δf, which is equal to 26.65 as a threshold.

Once people's Δf is bigger than the threshold, it means that he have the potential of fatty liver disease deteriorating.

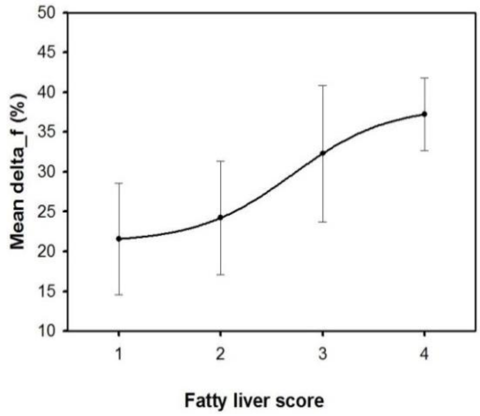

Figure 4. Ultrasound frequency change as a function of fatty score. With increasing the degree of fatty infiltration, the frequency decreases accordingly.

IV. CONCLUSION

In this paper, the proposed method based on STFT was tested on total 25 samples' liver data. The quantified frequency change parameter Δf 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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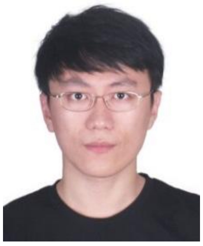
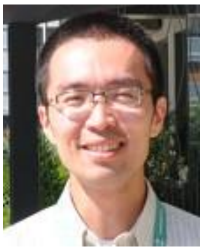


Chaojun Shou was born in Jiaxing, Zhejiang, China, in 1990. He received the B.S. degree in Communication Engineering College, Zhejiang Gongshang University, Hangzhou, China. He is now working on a master's degree in information and communication engineering, Zhejiang Gongshang University, Hangzhou, China. He participated a research exchange program in Chang Gung University, Taiwan in 2014-15 where his research is mainly on ultrasound imaging.

Xiaoyu Chen received the B.S. and M.S. degree from Nankai University, China, in 1984 and 1987 respectively. Then he received the Ph.D. degree in information and communication engineering, Zhejiang University, Hangzhou, China, in 2002.

He is the vice President of the institute of information and electronic engineering, Zhejiang Gongshang University, and signal and information technology institute.

Dr. Chen is a member of China electronic information branch society. He presided 3 national natural science foundation projects, 1 item of fund special talent in Zhejiang province. He has more than 40 academic theses being published, among them more than 20 academic theses with the first author have been published in IEEE TIT and other international mainstream academic journals of SCI. His research interests are quantum information processing and network information security, communications, information processing and intelligent information processing, etc.



Po-Hsiang Tsui was born in Taiwan. He received the B.E., M.S., and Ph.D. degrees in biomedical engineering from Chung Yuan Christian University, Chung Li, Taiwan, in 2000, 2001, and 2005, respectively, in 2006.

He was with the Research Center for Applied Sciences, Academia Sinica, Taipei, Taiwan, for postdoctoral research. In 2010, he joined Department of Medical Imaging and Radiological Sciences, College of Medicine, Chang Gung University, Taoyuan, Taiwan.

Dr. Tsui is currently the Associate Professor and the Director for Medical Imaging Research Center, Institute for Radiological Research, Chang Gung University and Hospital. His research interests focus on ultrasound scattering, parametric imaging, and tissue characterization.

HaoLi Liu received the Ph.D. degrees in Electrical Engineering in 2003 from the National Taiwan University, Taipei, Taiwan, in 2004 and 2005.

He was the research fellow of the Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA. He is currently the Professor and the Director of Department of Electrical Engineering, Chang-Gung University, Taoyuan, Taiwan, and also the Adjunct Assistant Researcher of Division of Medical Engineering Research, National Health Research Institutes, Miaoli, Taiwan.

Dr. Liu is currently continuing research in ultrasound thermal therapy and its treatment planning/simulation, ultrasound-induced blood brain barrier (BBB) disruption for brain drug delivery, ultrasound phased array design. Dr. Liu has published over 80 SCI papers (more than 10 are high ranked papers with the impact factors > 10), 19 USA/Taiwan patents in areas of biomedical use of therapeutic ultrasound. He received the Distinguished Tech-Coop Award (2011, 2014) and the Distinguished Research Award (2010) from Chang-Gung University, respectively. Also in 2011, He received the Wu Ta-You Memorial Award from the National Science Council in Taiwan. In 2013, he received the Frederic Lizzi Awardfrom the International Society for Therapeutic Ultrasound (ISTU) and also the Excellent Young Electrical Engineer Award from the Chinese Institute of Electrical Engineering to acknowledge his significant research contributions to therapeutic ultrasound. In 2015, as the first engineering-background honoree, Dr. Liu received the TienTe Lee Award to recognize his contribution on integrating medicine and engineering. Dr. Liu is a member of IEEE and International Society of Therapeutic Ultrasound (ISTU).