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Determining the Scattering of Ultrasound Waves Based On Weighted Entropy Analysis and Higher Order Statistics of Probability Density Function

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Abstract: *Ultrasound therapy can be effective in treating most injuries to the muscles and ligaments. B-mode ultrasound imaging is important because of its low cost, unsaturated radiation, time-of-use and extensive application. In some studies, Shannon entropy has been used to analyze radio frequency uncertainty (RF). Because entropy sensitivity is limited in the detection of different concentrations of dispersion, this feature can be used to find the amount of dispersion. Therefore, in this study, entropy weights is proposed as a new entropy-based approach to increase the scatter characterization function. In general, in this study, by extraction of two categories of entropy characteristics weighted and high-ranking individuals, the frequency density function of the RF amplitude of the RF signal before and after collision with the tissue, the concentration of focal beam dispersion was investigated. The magnitude of the Shannon entropy logarithm for radiation after radiation and during radiation irradiation before radiation in this study ranged from 1 to 1.1 for power of 70 and 90. 110 watts, which was modest and was almost constant for a power of 50 watts and did not make any significant changes.*

Keywords: *Ultrasound Waves, Weight Entropy, Shannon Entropy.*

INTRODUCTION

According to the census, ultrasonic waves are used more than other imaging methods, which on the one hand, certainly high safety and the lack of ionizing radiation, and on the other hand low cost and easy transportation, along with a rare features such as presentation the image as a real-time that is used mainly in surgery, are the use of this method although the weaknesses in this approach sometimes lead us to use a costly method such as MRI, or low safety method such as CT (Protopappas et al., 2006).
Generally, sound waves are a form of longitudinal mechanical waves and have a frequency of more than 20 kHz. The aim of the current study was to determine the rate of ultrasound scattering based on the weighted entropy analysis and higher order statistics of probability density function because these waves in humans caused changes in the hearing threshold and causing pain and suffering mentally and unusual fatigue and tissue lesions in the white blood cells of the blood (Protopappas et al., 2006).
One of the first studies of the effect of ultrasound stimulation on Neuroscience was reported by Frye et al (1958) (Zhou et al., 1992). They found that the ultrasound would lead to the reversible transmission stop along the neural pathways of evoked cortical potential, by an optical flash. Yang and Henman (1961) found

similar effects to guide in nerve fibers of mammals, and from 1976 to 1996 Gavilario et al. indicated that ultrasound can induce activity in human and animal neural structures (Hughes, 1993).
Firstly, Shannon offered a mathematical theory and defined entropy as measuring uncertainty in a random variable (Hughes et al., 2007). Initially, Hughes, via entropy information (Shannon), to analyze ultrasound signals indicated that entropy can quantitatively change the microstructure of scattering intermediates (Hughes, 2013). Moreover, entropy is a probability density function; so based on the distribution parameters, it can reflect the physical concept of post-scattering statistics (Nawrockia, 1986). In the article (Nawrockia, 1986), entropy measurement was evaluated and preliminary experiments disclosed that the Shannon Entropy standard estimation via RF raw data is not sensitive to variations in scattering concentration. Some studies done in other fields have revealed that standard entropy measurements may lose some vital information (Yang et al., 2005).
Compared to Shannon's conventional entropy, weighted entropy is a simultaneous measurement of probability and some weights (Khan and Bhuiyanm, 2014). In some of the preceding studies, it has been reported that weighted entropy has more efficient performance in data analysis and recognition compared to standard entropy (Guiasu, 1971). Focal ultrasounds waves are also used to stimulate cornea precisely and neuropathic (Shung and Thieme, 1993). This study was done to investigate the effect of focal ultrasound on the cornea. The ultrasound waves with low intensity and frequency have also been used to stimulate remote neural circuits (Tsui et al., 2009). Nature and ability to stimulate the nervous system in a non-invasive approach imply high therapeutic and laboratory capacity. In Mobasheri's et al. (2016) research, it is argued that concentrated ultrasound waves are an excellent treatment method used by researchers in recent decades. This is a successful and meaningful method as a non-invasive surgical technique used to treat tissue obstruction and cancer treatment. Since entropy sensitivity to detect the different density of scattering is limited, we used weighted entropy to determine the scattering of the concentrated beam in the tissue. Since the distribution of the probability density function of the amplitude of the photoacoustic signal is a normal distribution, in the case of scattering, by obtaining higher order statistics values (such as Skewness and kurtosis), we will be able to determine the degree of deviation from the symmetry and rippling of the signal during the scattering. Generally, in the current study, via these two categories of attributes, we will be able to determine the degree of deviation and scattering of the concentrated beam. Since the scattered beam damages the healthy tissue due to heat and burning the surrounding tissue, by investigating the scattering of tissue with two categories of the characteristics mentioned by probability density function of the photo acoustic signal, the magnitude of these scatterings may be detected and fixed.

Method

In this study, to determine the focal position of the concentric beam of ultrasound, at first from the RF signal, the diagram of probability density function (PDF) was drawn, which is the probability of incidence of a domain. Then, weighted entropy was obtained from the domain probability density function, which indicates that how much variation could be seen in the probability density function, or the higher order statistics property was extracted, which indicates the degree of uniformity and ripeness and the degree of deviation from the probability density distribution symmetry. Since the distribution of the probability density of the RF signal in the case of non-scattering has a normal distribution, by obtaining these two categories of characteristics, the probability density function of the signal domain before and after the burning the host tissue, the scattering rate was carefully examined.
The experimental part of the current study was conducted at the Advanced Therapy Laboratory and Ultrasound Imaging of Canada Ryerson University. An *ex vivo* examination on the fresh tissue of the pig's muscle was performed. The muscle samples are cut at 20 to 80 by 100 mm and degassed in deionized water at

5° C for 12 hours before the start of the test. An ultrasound imaging and array transducer with 128 elements, a 7 MHz core frequency, and a 3 MHz bandwidth for B-mode images and RF backscattering data were used. To produce B-mode images or two-dimensional images of a linear array, the ultrasound transducers scans a cross-section of the body in the direction of sending ultrasonic signals, and based on the received echoes, points are placed on a two-dimensional plane, and the brightness of these points is proportional to the received echo domain, consequently, a two-dimensional image of the desired texture is created.

Findings

Figure 1 reveals the Shannon entropy time domain in three steps (before, during and after) of concentrated ultrasound exposure.

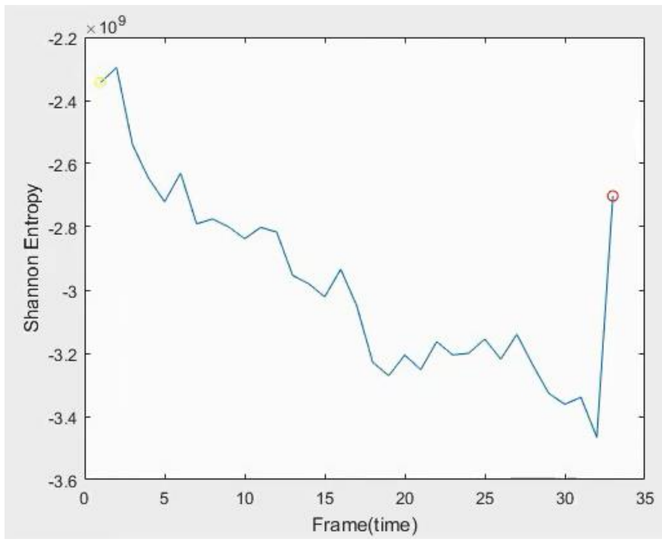

Figure 1: Shannon entropy time domain, before, after and during ultrasound radiation.

If instead of the Shannon entropy, the entropy logarithm value is replaced and the previous diagrams are plotted, it is perceived that the Shannon entropy logarithm time domain graph before and after and during the irradiation has great variations with the Shannon entropy diagram (Fig. 2). This type of entropy is better because it reflects the phenomenon of scattering better. The Shannon entropy logarithm values for after radiation and during radiation compared to before radiation range from 1 to 1.1 for the power of 70 and 90, 110 W, which had the slightest changes and they were almost constant for a power of 50 W and did not have any significant changes.

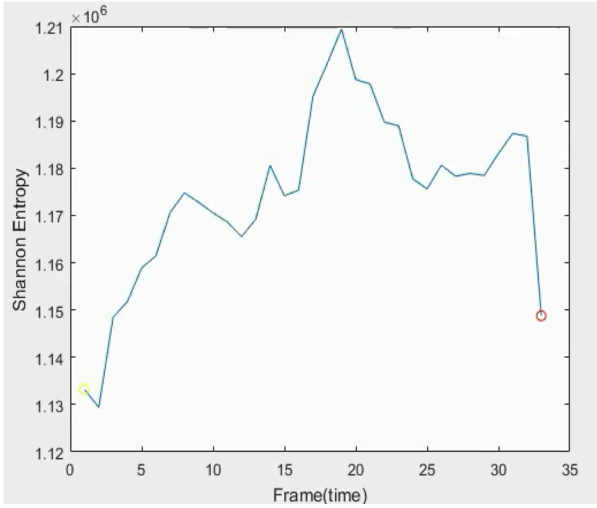

Figure 2: Shannon entropy logarithm time domain before, after and during ultrasound radiation (70 W)

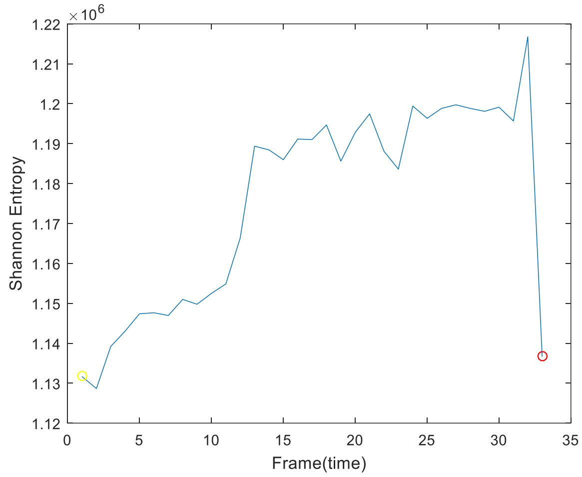

Figure 3: Shannon entropy logarithm time domain before and after concentrated ultrasound radiation (90 W)

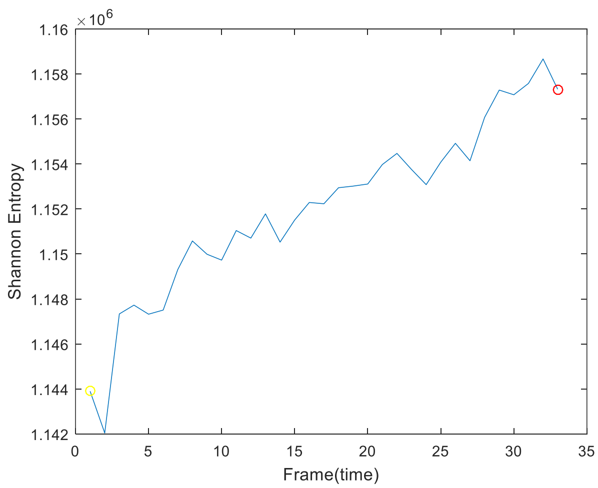

Figure 4: Shannon entropy logarithm time domain before and after and during concentrated ultrasound radiation (50 W)

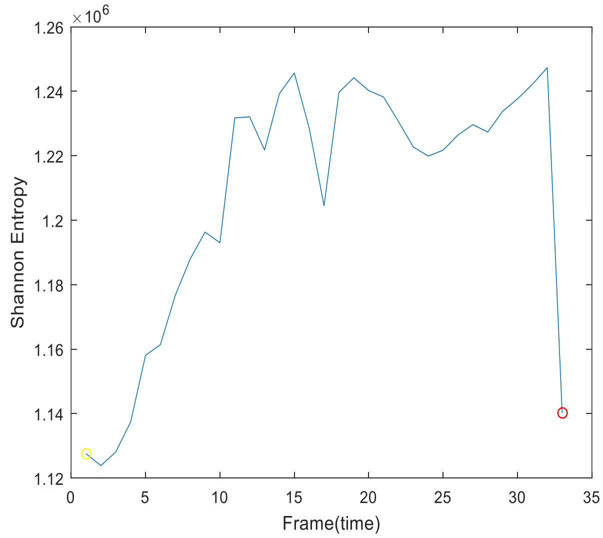

Figure 5: Shannon entropy logarithm time domain before and after and during concentrated ultrasound radiation (110 W)

If again the smooth mode entropy is considered, so that the value of smooth mode is 2, then the diagrams of the time domain of the smooth entropy are obtained before and after the radiation in the Figure (6). Approximately results were obtained as the first case.

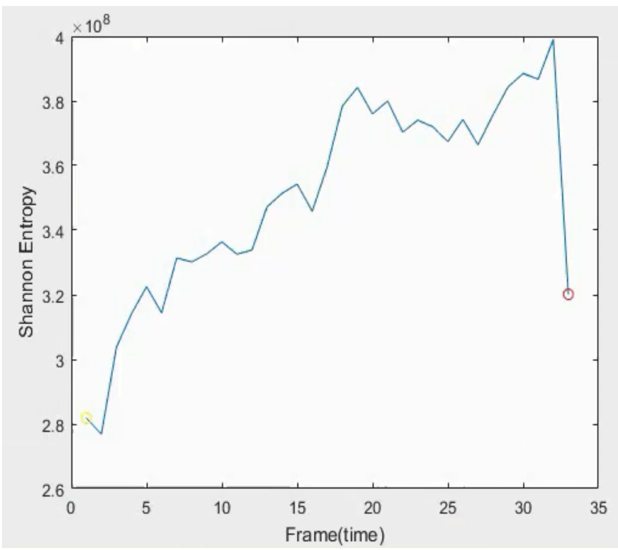

Figure 6: Shannon entropy smooth time frame 2 before, after and during concentrated ultrasound radiation (70 W)

If we change the smooth value from 2 to 1, we can see the changes in the graphs shown above, which are in the form of Figure (7). The results were analyzed for the power of 50, 70, 90 and 110 W.

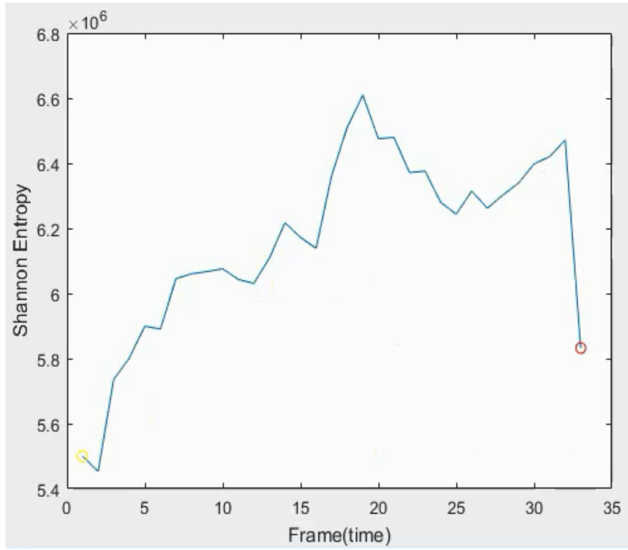

Figure 7: Shannon entropy smooth time domain 1 before and after and during concentrated ultrasound radiation (70 W)

Once again, we choose the *sure* type of Shannon entropy degree of confidence and grade 3, and the previous diagrams were obtained as Figure 8.

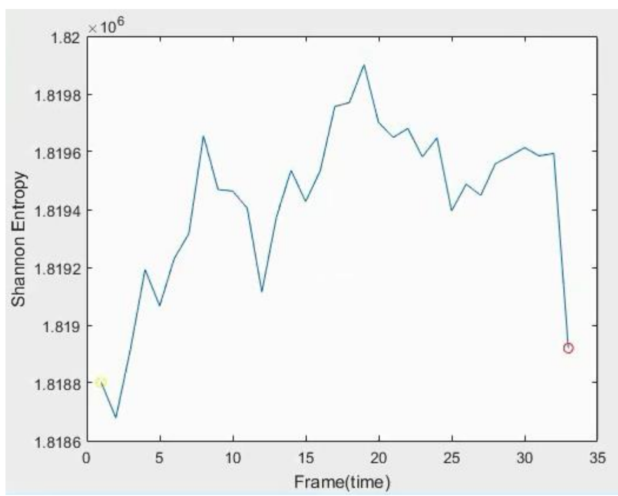

Figure 8: Time frame of the *sure* degree of confidence with grade 3 Shannon Entropy before, after and during concentrated ultrasound radiation (70 W)

In the following, by averaging the extracted properties for after and during radiation, the power spectrum density diagrams were plotted in Figures 9, 10, 11 and 12.

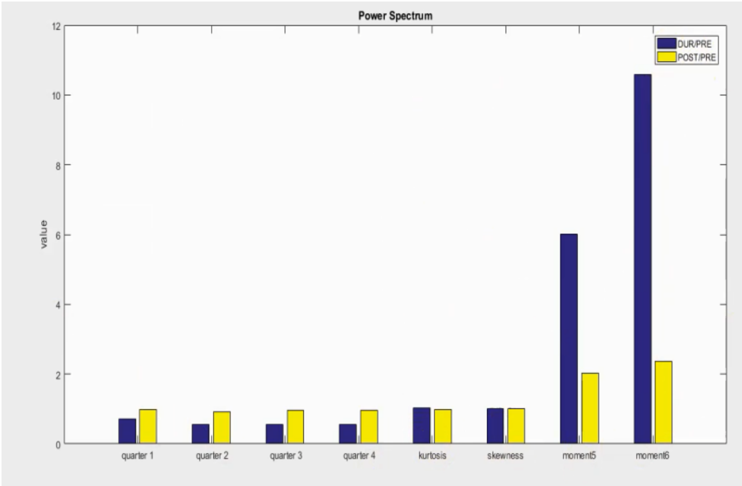

Figure 9: Power spectrum density diagram for DUR/PRE and POST/PRE modes for various features (70 W)

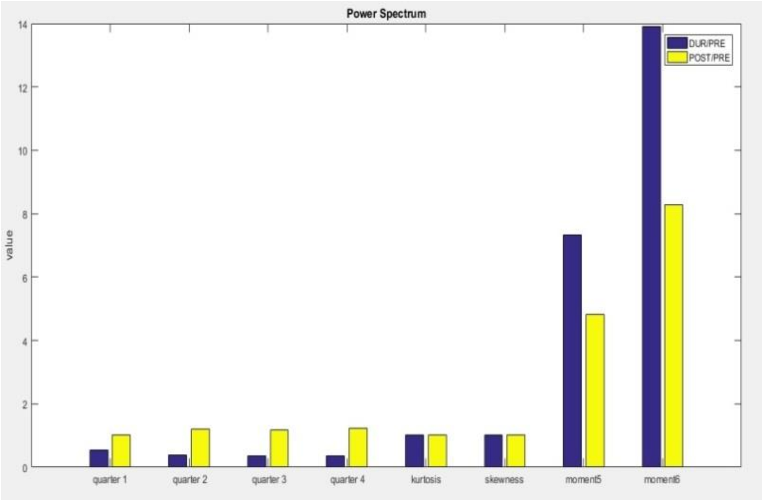

Figure 10: Power spectrum density diagram for DUR/PRE and POST/PRE modes for various features (90 W)

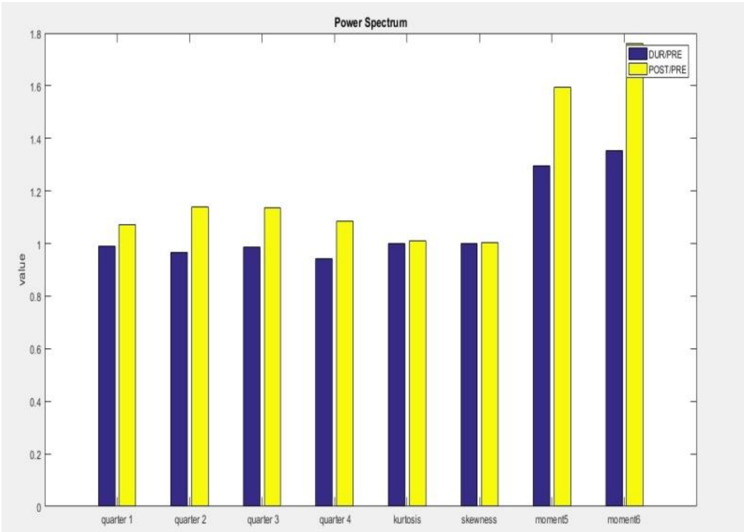

Figure 11: Power spectrum density diagram for DUR/PRE and POST/PRE modes for different features (50 W)

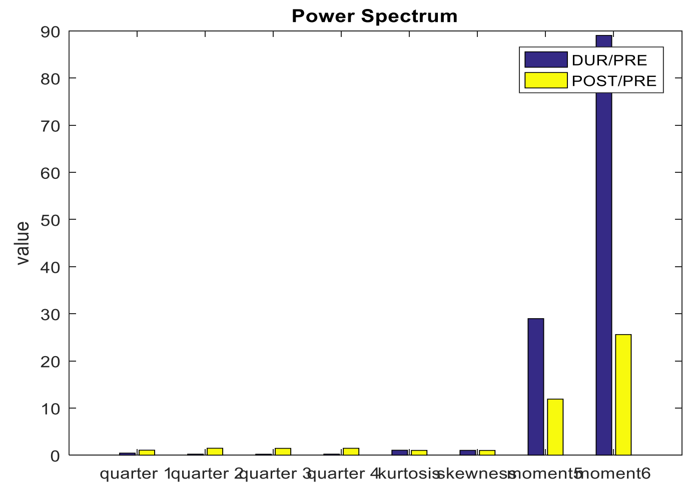

Figure 12: Power spectrum density diagram for DUR / PRE and POST / PRE modes for different features (110 W)

As shown in Figures 9 to 12, higher-order torque features such as grades 5 and 6 have a higher differentiation power to show the amount of scattering, because the power spectrum density is higher for these features. From the above diagram, it can also be concluded that the amount of entropy is increasing during radiation.
These diagrams are the power spectrum density diagrams that generally, for each density feature of the power spectrum, it was once calculated during irradiation and once before radiation after the calculated radiation, and for different modes, the rate of the density domain of the power spectrum has been investigated, for instance, the blue color of the diagram is for the time when the domain was the duration of radiation and the yellow color was for domain after ultrasound radiation. As indicated in the previous section, the results were appropriate for the features of the 5 and 6-degree torques, because they have a higher degree of differentiation to find the amount of scattering.

Conclusion

In this study, via extraction of two categories of the weighted entropy and the higher order statistics from the probability density function of the photoacoustic signal amplitude degree of diffusion before and after the collision with the tissue, the concentration of focal beam diffusion is investigated. In general, at first, obtained the signal amplitude in both the before and after tissue burning modes, and drew the probability density function (frequency per frame values), which must be a Gaussian diagram, and based on the calculation of the skewness features that reveals the deviation from the symmetry and the kurtosis which gives the level of signal smoothness and rippling signals, and the degree of irregularity of the scattering is calculated in both cases.
Since entropy sensitivity is limited in the detection of different concentrations of scattering. In the current study, the weighted entropy was used to determine the concentrated beam concentration in the tissue. Since the distribution of the probability density function of the amplitude of the RF signal is a normal distribution, in the case of scattering by obtaining high order statistics values (such as skewness and kurtosis), we will be able to detect the degree of distortion of the symmetry and rippling of the signal during the scattering. Generally, in the current study, via these two categories of features, we will be able to determine the degree of scattering and diffusion of the concentrated beam. Since the scattered beam due to the created heat and the burning surrounding tissues, the healthy tissue would be damaged; by measuring the scattering of tissue with

two categories of the mentioned features by the probability density function the amplitude of the photoacoustic signal the magnitude of these scatterings may be detected and fixed.

Primarily, Shannon presented a mathematical theory and defined entropy as an uncertainty measurement in a random variable. At first, Hughes, using the entropy information (Shannon) to analyze ultrasound signals, indicated that entropy can determine the microstructure of scattering intermediates quantitatively. Also, entropy is a probability density function, so it can reflect the distribution parameters of the physical concept of backscattering statistics. Compared to the distribution parameters, entropy is estimated via the waveform of the distributed radio ultrasound raw data (RF).

In the article (Mobasheri et al., 2016), entropy measurement was evaluated and preliminary experiments indicated that the standard estimation of Shannon Entropy via RF raw data is not sensitive to variations in scattering concentration. The low sensitivity of the parameter during the process of detecting the concentration of scattering limits the function of tissue characterization. Some studies in other fields have shown that standard entropy measurement may lose some crucial information (Khan and Bhuiyan, 2014; Guiasu, 1971).

Compared to Shannon's conventional entropy, weighted entropy is a simultaneous measurement of probability and some weights (Lai, Khan and Poh, 2012). In some of the previous studies, it has been reported that weighted entropy is more efficient in data analysis and recognition than standard entropy (Yeung et al., 2002; Sadeghi et al., 2011; Shung and Thieme, 1993). In Tsui et al. (2009) research, weighted entropy has been introduced to detect the ultrasound wave scattering. A standard simulation model of ultrasound scattering is used to generate scattered RF ultrasound signals with different values of scattering density. The RF signals were used to estimate the weighted entropy according to the proposed algorithm. When the density of scatterers increased from 2 to 32 scatterings per milliard cubic meter, the value of weighed entropy increased from 0.08 to 0.23. The results disclosed that weighted entropy provides greater sensitivity to detect changes in ultrasound scattering concentration.

In Mobashari's et al. (2016) research, radio ultrasound signals (RF) were recorded in three steps before, during and after exposure to HIFU. Different RF features of the time series signals consist of the sum of the amplitude range in four frequency ranges, slope and the most suitable accommodation line to the entire power spectrum and Shannon entropy for the detection of HIFU induced the heat loss and natural tissue. Also, RF data in frame-to-frame setup was used to recognize the effects of exposure and features of HIFU's lesion in different stages during treatment. The obtained results revealed that the frequency range of the power spectrum was doubled, and the slope and best proportionality line with the entire power spectrum increased during HIFU radiation. However, the Shannon entropy is reduced after exposure. As a result, different features of the RF time series signal have promising features that can be used to describe fragmented and non-abstract textures and divide them quantitatively. HIFU radiation was performed for 5 different muscle tissues. The PRE-HIFU data was first stored and then HIFU radiation was performed for 40 seconds. Data were recorded during HIFU radiation. In the last step, 10 minutes after the HIFU radiation recording, it was turned off and the POST-HIFU data was recorded. During the HIFU radiation, bubbles were generated at the locations of lesions. Generally, the characteristics of thermal lesions were obtained with HIFU radiation, including the density of the power spectrum and the Shannon entropy. The results of this study indicated that DUR-HIFU values were higher than PRE-HIFU with an electrical power ratio of 75 W at 1, and the POST-HIFU rate was higher than PRE-HIFU radiation and it was equal to 0.5, while the DUR-HIFU value higher than PRE -HIFU with an electrical power of 90 W was equal to 0.9 and POST-HIFU higher than PRE-HIFU was equal to 0.8.

By comparing the results of Mobasheri's (2016) paper and the results of this study, it can be seen that higher-order features have higher differentiation power than the entropy rate to determine the amount of radiation scattering and, on the other hand, entropy types such as smooth and SURE are better than the typical Shannon entropy in Mobasheri's paper can determine the amount of scattering. So, using high order statistical features increased the accuracy in determining the distribution of HIFU radiation compared to other articles. The comparison revealed that the magnitude of the calculated Shannon entropy logarithm after radiation was less and better than before radiation, and the rates of the values obtained were higher in the Mobasheri's paper.

In Sadeghi's et al. (2011) research it argued that ultrasound elastography is a non-invasive method that illustrates the distribution of elasticity in smooth tissues. To make the image, the RF signals are obtained before and after exerting the pressure on the tissue, and the time delay between them is estimated; then the strain is calculated from these time delays, and its distribution is portrayed as an elastic image. In the current paper, via a new method of processing called empirical decomposition, which is used to decompose a complex signal into a set of simpler signals, IMF, decomposes signals before and after compression, and instead of the main signal in the process of estimating displacement, the IMFs were used. To estimate the displacement, two methods of cross-correlation and violet have been used. The calculation of signal-to-noise, SNR, and contrast-to-noise CNR, as the image quality measurements, shows that in both methods after using CNR, EMD and SNR are increased, and its value in a cross-correlation method is about 5.17dB and 10dB and in the violet method is about 11dB and 9dB, respectively.

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