# Denoising of Echocardiograms using Wavelet Shrinkage

Kenta Nakayama, Wataru Ohyama, Tetsushi Wakabayashi, Fumitaka Kimura[1] and Kiyotsugu Sekioka[2]

[1] Graduate School of Engineering, Mie University, Tsu, Japan
[2] Sekioka Clinic, Minami–Ise, Japan

*Abstract*— **We propose a new speckle reduction algorithm for clinical echocardiograms. The proposed method employs Wavelet Shrinkage to reduce the noise on an ultrasonic signal. In the wavelet shrinkage, at first, original ultrasonic signal is decomposed into wavelet coefficients by multiresolution decomposition using orthogonal wavelet. A threshold of which objective is suppression of noise component is estimated on the resultant complex wavelet coefficient. Wavelet coefficients corresponding to noise are eliminated by soft–thresholding. The noise reduction by the wavelet shrinkage can remove specific frequency components. In this study, we employed the RI-Spline wavelet that was proposed as a shift-invariant mother wavelet. We conducted experiments using clinical ultrasonic signals to evaluate the noise reduction performance of the proposed method. Ten clinical subjects were used in the experiments. The experimental results show that the algorithm provides superior performance on speckle and noise reduction compared to that of existing speckle reduction method.**

*Keywords*— **Echocardiogram, Ultrasound, Wavelet Shrinkage, Speckle Reduction.**

## I. Introduction

An echocardiograph has built its strong position in today's diagnosis of the cardiovascular system as an indispensable imaging device. Its frequently usage is a result from its multifold advantages in cardiovascular performance assessment. Using an echocardiograph provides us noninvasive, low–cost, portable and real–time assessments of heart.

However, echocardiograms contain certain amount of speckles and noise due to the inherent property of ultrasound. These speckles and noise not only degrade the image quality of echocardiograms but make clinical diagnosis based on echocardiography difficult. To obtain enough quality of images, doctors or ultrasonologists should adjust several parameters like dynamic range or time gain compensation using a control panel of ultrasonic equipment. Though speckles and random noise appearing in the heart chamber can be removed by eliminating small amplitude using the reject–level control, the homogeneous influence of the reject–level control to the all ultrasonic signal also removes meaning appearance in myocardium. To improve clinical diagnosis, automatic reducing speckles and enhancing image quality are required.

Several methods intending to improve image quality of echocardiograms have been proposed. Zong *et.al* [1] proposed an algorithm for speckle reduction and contrast enhancement of echocardiograms. They applied a multi-scale wavelet shrinkage to eliminate noise and employed a nonlinear processing of feature energy to enhance contrast of images. Yue *et.al* [2] proposed a multiscale wavelet diffusion method for speckle suppression and edge enhancement. These methods subjected two–dimensional echocardiograms acquired using a ultrasonic diagnosis equipment. This means that these methods behave as a post–process which follows image generation process in an echocardiograph so that they oversimplify the images.

In contrast to these two–dimensional echocardiogram based methods, we propose a new noise reduction method subjecting the radio–frequency (RF) signal of ultrasound. The method employs Discrete Wavelet Transform (DWT) where the Real–Imaginary Spline Wavelet (RI–Spline wavelet)[3] is used as a mother wavelet. For noise reduction, Wavelet Shrinkage [4] is widely used by its simple usage. However, since the ordinary DWT has a problem of which the translation invariance is lacking, artifacts is generated. The RI–Spline wavelet has been developed to overcome this problem of DWT.

The paper is organized as follows. In section II, the proposed speckle reduction method is described. In this section, we explain how the method suppresses the speckle in ultrasonic RF signals. Availability of the proposed noise reduction method is observed and evaluated in section III. And finally, we conclude the paper in section IV.

## II. Speckle reduction of echocardiogram

In this section, we explain our proposed noise reduction method employing the DWT with RI–Spline wavelet on the ultrasonic RF signals.

### A. Ultrasonic Data Acquisition

Fig.1 illustrates the system used for ultrasonic RF data

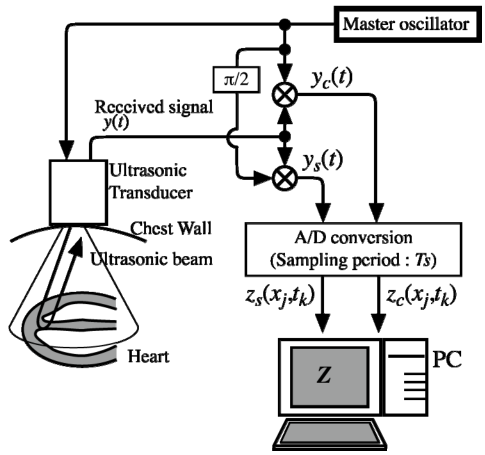



Fig. 1 Data acquisition system

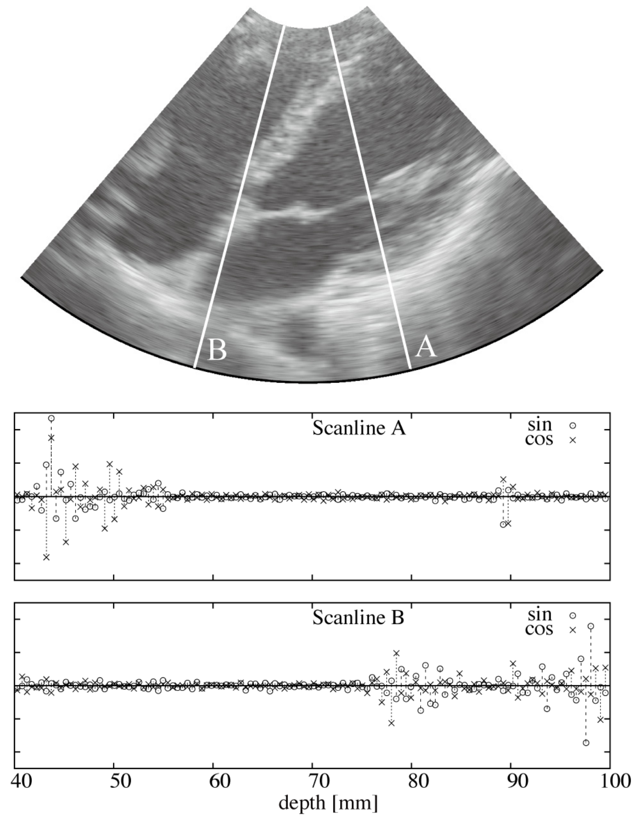



Fig. 2 Example of acquired ultrasonic data (lower) and ultrasonic image generated from the data (upper)

acquisition. An ultrasonic transducer placed on the chest transmits pulsed ultrasonic toward the heart, and receives the backscattered ultrasonic. The transducer coverts the received ultrasound to electric signal $y(t)$.

The electric signal $y(t)$ is quadrature demodulated and-then A/D conveted to be imported to PC as discrete ultrasonic signal $\boldsymbol{Z} = \{z(n,m)\}$. The ultrasonic signal $z(n,m)$ is expressed as follows,

$$z(n,m) = z_s(n,m) + jz_c(n,m) \tag{1}$$

where $z_s$ and $z_c$ denote the sine and cosine components obtained by the orthogonal demodulation. $n$ and $m$ denote the radial and angular indices of the B–scan sector image samples, respectively. The location of the sampling point indicated by $(n,m)$ is defined as,

$$x_n = nc_0T_s,$$

$$\psi_m = m\Delta\psi, \tag{2}$$

where $x_n$ and $\psi_m$ denote the distance and angle from ultrasonic transducer. The constant $C_0$ is sound velocity in human body, i.e. 1530 [m/s]. $T_s$ and $\Delta\psi$ are sampling period and angle interval, respectively.

Fig.2 illustrates an example of acquired ultrasonic data and an ultrasonic B–scan image generated from the ultrasonic data. In the figure, the signals located on the lower part exhibit original ultrasonic signal $\boldsymbol{Z}$ on the scan–lines A and B, which are displayed by the white lines in the image.

*B. Noise Reduction by Wavelet Shrinkage*

The noise reduction process in the proposed method consists of three main stages. In the first stage, the original ultrasonic signal is decomposed into complex wavelet coefficients by Complex Multi–Resolution Analysis (CMRA) with RI–Spline wavelet. In the next stage, Soft–Thresholding is applied on the wavelet coefficients to eliminate the noise components. And finally, de–noised ultrasonic signal is synthesized from the wavelet coefficients after Soft–Thresholding. Using the CMRA, a wavelet coefficient is expressed as a pair of coefficient. The each of them is corresponding to the real and imaginary parts of synthetic wavelet:

$$d^r_{k,l}\psi^r_{k,l}(t) + d^i_{k,l}\psi^i_{k,l}(t) \tag{3}$$

This equation denotes the synthetic wavelet on the level $k$ and shift $l$.

To accomplish the wavelet shrinkage using such complex coefficients, we should calculated the norm $n_{k,l}$ of the synthetic wavelet by follows:

$$n_{k,l} = \sqrt{\left(d^r_{k,l}\right)^2 + \left(d^i_{k,l}\right)^2}\ , \tag{4}$$

Where $d_{k,l}^{r}$ and $d_{k,l}^{i}$ denote the real and imaginary part of wavelet coefficient. The threshold for noise reduction is estimated on the level–1 (highest–frequency) wavelet coefficients. The noise magnitude in the signal is estimated using the following:

$$\delta = \frac{Median\left(\left|n_{-1,l} - Median\left(n_{-1,l}\right)\right|\right)}{0.6745}, \quad (5)$$

where, Median($n_l$) denote the median of $\left\{ n_l \mid l = 1,2,3,\ldots,\frac{L}{2} \right\}$. Using estimated noise magnitude, we obtain the threshold,

$$\lambda = \delta\sqrt{2\ln L} \quad (6)$$

where $L$ denotes the number of sampling point on one scan–line.

Obtained threshold is applied in the soft thresholding process following the CMRA. The soft thresholding process is defined as:

$$\dot{n}_l = \begin{cases} n_l - \lambda, & n_l \geq \lambda \\ 0, & n_l < \lambda \end{cases} \quad (7)$$

Prior to the reconstruction process, we should transform $\dot{n}_l$ to wavelet coefficients using:

$$\dot{d}_{k,l}^{r} = \frac{\dot{n}_{k,l}}{n_{k,l}} d_{k,l}^{r}$$
$$\dot{d}_{k,l}^{i} = \frac{\dot{n}_{k,l}}{n_{k,l}} d_{k,l}^{i} \quad (8)$$

## III. Experiments and results

To demonstrate and evaluate the noise reduction performance of the proposed method, we conducted an experiment using clinical ultrasonic data. The set of test ultrasonic data were acquired using an ultrasonic diagnose system (Hitachi–Medical EUB–6500). One ultrasonic data is corresponding to one systolic and diastolic sequence of echocardiogram. Ten data sets were subjected to the experiment.

Fig.3 exhibits three examples of experimental result. The upper three images are ultrasonic images generated from original ultrasonic data. These examples contain a certain amount of speckle in both cavity and myocardium regions. The lower three are ultrasonic images generated with the proposed noise reduction. One can see that the speckles in cavity and myocardium regions are reduced and the contrast of images are enhanced.

To quantify the effectiveness of noise reduction, we conducted the following evaluation process. We evaluate the image quality using the following signal to noise ratio.

$$\mathrm{SNR} = \frac{\left|\bar{f}_m - \bar{f}_c\right|}{\sigma_B} \quad (9)$$

Table 1 Image quality measure obtained in the evaluation experiment using different noise reduction method

| | Original | with noise reduction |
|---|---|---|
| SNR | 4.22 | 5.11 |

where, $\bar{f}_m$ and $\bar{f}_c$ denote the mean pixel value in the regions corresponding to myocardium and cavity, respectively. $\sigma_B$ denotes the standard deviation of pixel value in the generated ultrasonic image calculated by:

$$\sigma_B = \sqrt{\frac{\omega_c\sigma_c^2 + \omega_m\sigma_m^2}{\omega_c + \omega_m}} \quad (10)$$

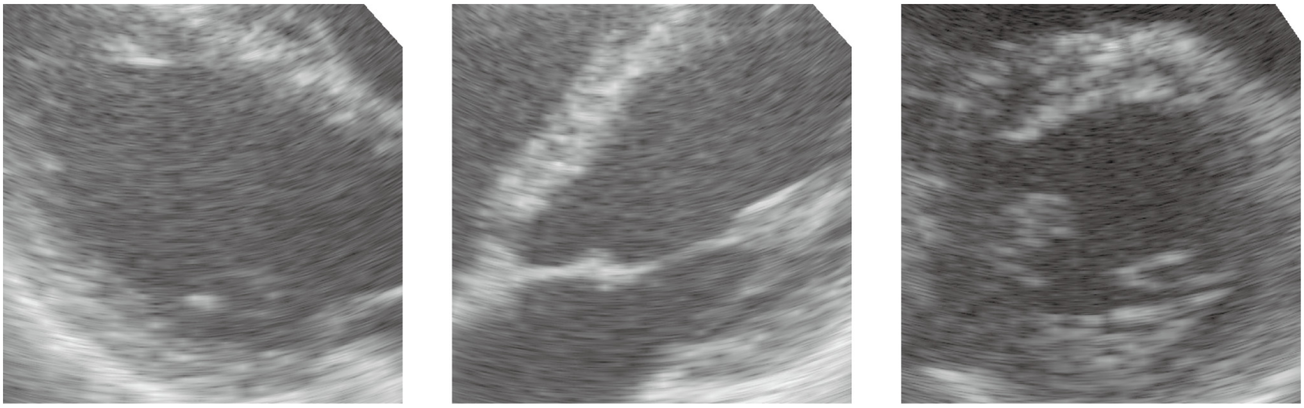
where, $\sigma_c$ and $\sigma_m$ denote the standard deviation of pixel value in the myocardium and cavity regions, and $\omega_m$ and $\omega_c$ denote the area (number of pixel) of myocardium and cavity, respectively. The myocardium and cavity regions are extracted manually on the generated ultrasonic images.

The evaluation experiment subjected ten ultrasonic images generated with and without the proposed noise reduction method. Table.1 shows the comparison between two methods. One can see that the SNR is improved by the proposed noise reduction method.

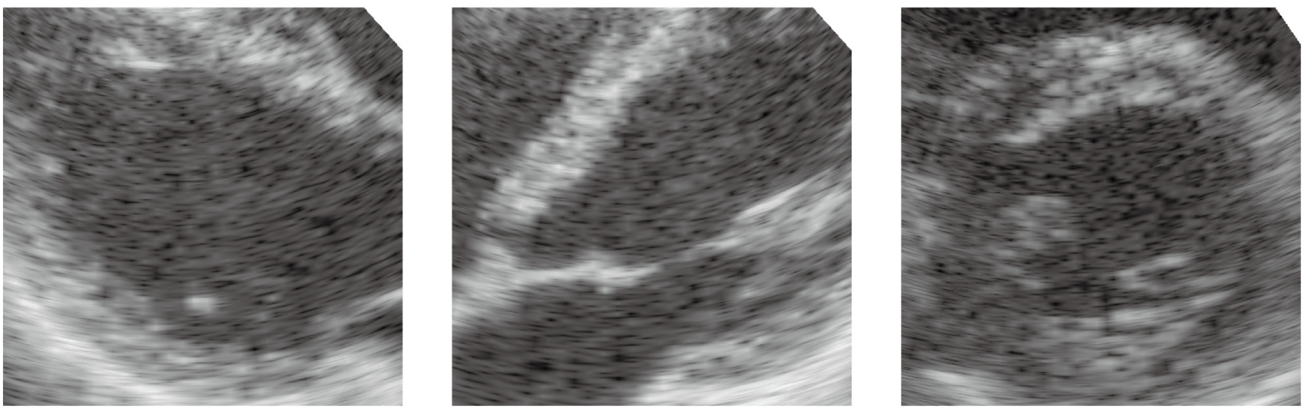
## IV. Conclusions

We proposed a new noise reduction method for echocardiograms. The proposed method employs the wavelet shrinkage which using the RI–Spline wavelet as the analyzing wavelet.

The future research topics include (1) detailed comparisons among the proposed method and other noise reduction method for image quality, and (2) improvement of processing speed.



(a) Ultrasonic images generated from ordinary ultrasonic signal



(b) Ultrasonic images generated from ultrasonic signal with noise reduction

Fig. 3 Visual comparison of noise reduction performance

## References


[1] Xuli Zong, Andrew F. Laine, and Edward A. Geiser. Speckle reduction and contrast enhancement of echocardiograms via multiscale nonlinear processing. *IEEE Transactions of Medical Imaging*, 17(4):532–540, August 1998.

[2] Yong Yue, Mihai M. Croitoru, akhil Bidani, Joseph B. Zwischenberger, and Jr John W. Clark. Nonlinear multiscale wavelet diffusion for speckle suppression and edge enhancement in ultrasound images. *IEEE Transactions of Medical Imaging*, 25(3):297–311, March 2006.

[3] Zhong Zhang, Hiroshi Tada, Satoshi Horihata, and Tetsuo Miyake. Nonstationary signal analysis using the ri–spline wavelet. *Integrated Computer–Aided Engineering*, 13:149–161, 2006.

[4] D.L. Donoho. De–noising by soft–threholding. *IEEE Transactions of Infomation Theory*, 41:613–627, 1995