論 文
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回歸方法에 의한 超音波 診斷器의 側面解想度 改善에 관한 硏究

A Recursive Scheme for Improvement of the Lateral Resolution in B-scan Ultrasonography

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Abstract

The objective of this paper is to present a digital method for improving the lateral resolution of the B-scan images in the medical applications of ultrasound. The method is based upon a mathematical model of the lateral blurring caused by the finite beam width of the transducers. This model provides a simple method of applying a recursive scheme for image restoration with fast computation time. The point spread function (P.S.F.) can be measured by the reflective signals after scanning the small pins located along the dpeth of interest. From the measured P.S.F., one can compute the coefficient matrices of the inverse discrete-time dynamic state variable equation of the blurring process. Then, a recursive scheme for deblurring is applied to the recorded B-scan to improve the lateral resolution. One major advantage of the present recursive scheme over the transform method is in its applicability for the space-variant imaging, such as in the case of the rotational movement of transducer.

1. Introduction

In medical application of ultrasound, the B-scan ultrasonography is the most widely used non-invasive diagnostic method, as it provides the cross-sectional images of soft tissue with the transducer movement over the body surface. One major cause of image degradation in B-scanning mode is known as the lateral blurring in transducer movement with a finite beam width.

When the transmitted beam width is broader than the object size, the B-scan ultrasonographic image has a limited lateral resolution due to the spatial variation of the beam profile across the transducer area. As this lateral blur can be expressed as a convolution sum of the beam profile with the true object image, the inverse filtering methods for digital deconvolution have been used to improve the resolution up to 50 percent by Hundt and Trautenberg[1] and for C-mode by Ken-Ichi Ito et al[2].

In the above Hundt's study, the digital filter for deconvolution was constructed from the measured signal amplitude reflected from a point reflector. Then, the filter function was empirically smoothed by a Gaussian function to eliminate the peaks in the high frequency ranges. Because of this modification of the frequency spectrum of the beam profile,

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the filtered image is only an approximation of the object's reflection coefficient, and the accuracy of approximation is different depending upon the selected smoothing function.

In the present study, we have used a recursive scheme to restore exactly the object image from the blurred ultrasonic B-scan image by employing a discrete-time state-space model of the lateral blur and the measurement of the point spread function (PSF).

2. Analysis

In the B-scan ultrasound imaging systems, a location in the vertical coordinate, Y, is determined by the total time delay, τ, of the returning signal after reflection at the objects as follows;

$Y=C\tau/2$

where C is the propagation velocity of the ultrasound signal in soft tissue. Also, a specific location in the horizontal coordinate, X, is determined by the position of the mechanical arm's potentiometer depending upon the transducer location. Then, the amplitude of the reflective signal is digitized and rectified to determine the intensity levels of the

Fig. 1. A typical B-scan ultrasonography image of abdomen area

image display system. In the present study, the reflected lateral profile of the object image on a single horizontal line is modeled as a noise-free, space-invariant motion blur problem. This model can be applied, when we assume that the human tissue has linear property for the ultrasound propagation and reflection and that the ultrasound transducer has auniform finite beam width. Then, using the digital restoration, method of images degraded by motion blur, reported by various investigators [3,4], the intensity of the recorded image $R(n, k)$ at point k on line n is given by the following convolution summation;

$$R(n,\ k)=\sum_{l=-m_1}^{m_2} H(l)\ Q(n,\ k-l) \tag{1}$$

$$n,\ k=0,1,2,\cdots\cdots,\ N-1.$$

where $m_1,\ m_2\geq 0$ indicate the extent of blur at line n as shown in Fig. 2, and N is the number of pixels in stored image frame. The values of $H(l)$ for $l=-m_1,\cdots m_2$, define the PSF, and can be measured by the intensity of a point reflector image. $Q(n,\ l)$ is the object image located at a horizontal position l and on the vertical spatial location n. In noncausal case of $H(-m_1)\neq 0$, $Eq(1)$ can be converted to a causal form as follows;

$$R(n,k)=\sum_{i=0}^{m} f_i D^i\ Q(n,\ k+m_1) \tag{2}$$

where $\quad f_i=H(i-m_1)$

$\qquad D^iQ(n,\ k)=Q(n,\ k-i)$

$\qquad m=m_1+m_2$

Then, $R(n,\ k)$ can be expressed as follows,

$$R(n,\ k)=H(D)\ Q(n,\ k+m_1) \tag{3}$$

where $\quad H(\mathrm{D})=\sum_{i=0}^{m} f_i D^i$

In Eq. (3), m_1 indicates a degree of noncausality of the blur, as shown in Fig. 2. Eq. (3) shows that the blurring process can be expressed as causal operation $H(D)$ on an advance-shifted version of input Q.

The above convolution summation can be equivalently represented by a single input single output discrete state-space system of order m;

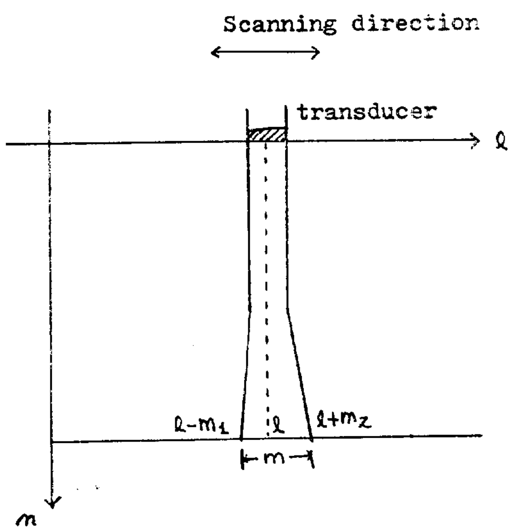


Fig. 2. A beam profile of the transducer

$$
\begin{aligned}
&x(n,\ k+1)=Ax(n,\ k)+BQ(n,\ k+m_1)\\
&R(n,\ k)=Cx(n,\ k)+dQ(n,\ k+m_1)\qquad (4)\\
&x(n,\ 0)=Xn\\
&k,\ n=0,1,2,\cdots\cdots,\ N-1.
\end{aligned}
$$

where system matrices A, B, C, d, and initial condition can be computed from the knowledge of PSF and the background intensity[5].

The restoration of the object image can be accomplished in Eq. (5) by computing the recursive inverse to Eq. (4);

$$
\begin{aligned}
&z(n,\ k+1)=\hat{A}z(n,\ k)\ +\hat{B}R(n,\ k)\\
&Q(n,\ k+m_1)=\hat{C}z(n,\ k)+d\ R(n,\ k)\qquad (5)\\
&z(n,\ 0)=Xn\\
&n,\ k=0,1,2,\ \cdots\cdots,\ N-1.
\end{aligned}
$$

where $\hat{A}=A-Bd^{-1}C$, $\hat{B}=Bd^{-1}$, $\hat{C}=-d^{-1}$, $d=d^{-1}$ and $Zn=Xn$.

In the present study the horizontal scan is only considered for simplification of analysis. However, any perpendicular movement of the transducers with respect to the scanning direction would not affect the present analysis, since the change of PSF along the vertical direction was shown to be small[1].

3. Experiment and Result

An ultrasonography digital imager (Picker, Model 80L-DI) interfaced with DEC MINC-11 computer

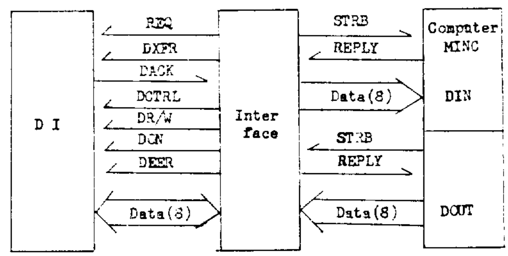
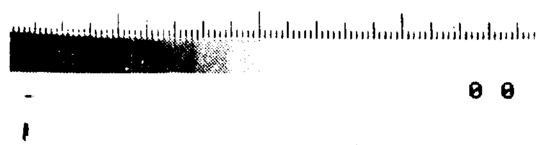
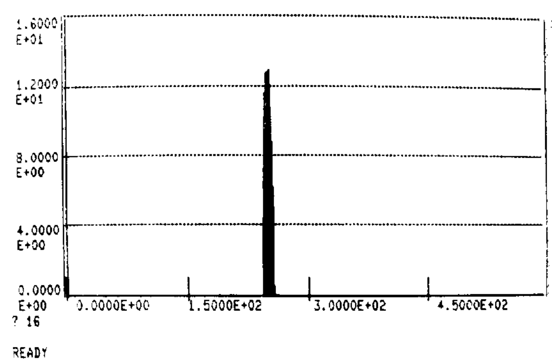


Fig. 3. Interface signals between ultrasound digital imager and computer



(a)



(b)

Fig. 4 (a). An image obtained by scanning a point reflector located at 6cm depth

(b). Digital values of the point spread function, averaged from seven scans

was used for processing of the 480×480 pixel data with 16 gray levels (4 bits) to access the image-data in digital imager, a floppy disc interfac bus was used[6]. The scanning was performed using a 5 MHz unfocused disc type transducer (19mm diameter). The average value of several scans was used for determination of PSF and A, B, C, d matrices with zero initial state (zero background).

A B-scan image is shown in Fig. 4-a for the reflected image of a pin (0.6mm diameter) located at 6cm depth in a water phantom. Fig. 4-b ghows the averaged values of a lateral profile of the center line of the above single pin. This profile has been used as the measured point spread function for

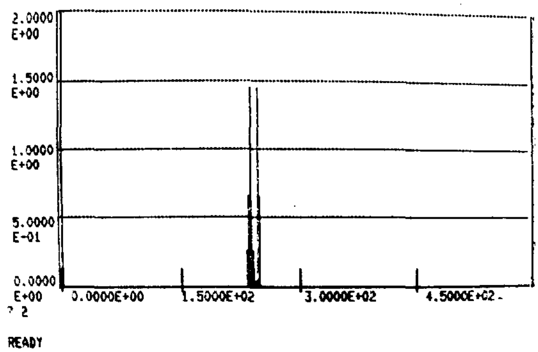
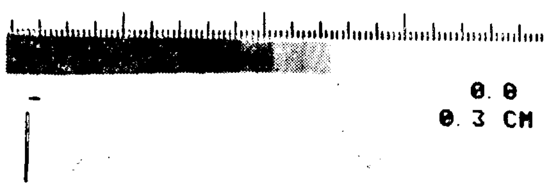


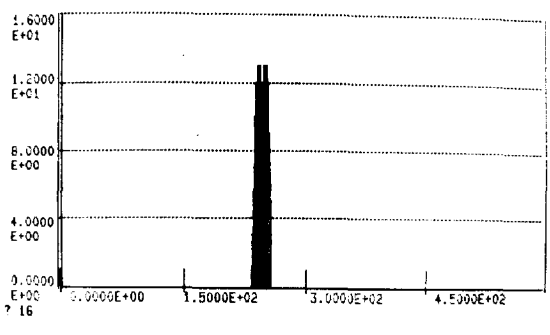
Fig. 6. A recursively processed digital values of the same pin image of Fig. 5. The final data was squared to correct the ringing effect

computation.

The B-scan image of two pins (0.6mm dia.) located 3mm apart at 6cm depth in water is shown in Fig. 5-a. and its corresponding lateral profile is shown in Fig. 5-b. Fig. 6 shows the lateral profile of the same two pins after restoration processing. While the centers of two pins could not be separated in this original blurred profile of Fig. 5, the two pins could be clearly separated in Fig. 6 after the digital recursive processing.



(a)



(b)

Fig. 5 (a). Image obtained by scanning two pins 3mm apart located at 6cm depth. Two dots shown above the image are the digital caliper output indicating the distance between two points on image surface shown in the lower rigth corner

(b) Digital values of the gray level at the center line of the pin image in Fig. 5(a)

4. Discussion

In the present phantom study, the lateral resolution was shown to be improved after performing recursive processing on the B-scan images. A discrete state-space dynamical model of the horizontal blur and the measured point spread function were used to find the exact object images in noise-free case, as compared with the modified inverse filtering method in which an approximation was obtained.

Before application of the present method to the clinical measurement, the following problems should be considered; 1) vertical correlation in addition to lateral correlation, 2) space variance in the rotational scanning, 3) noise in measurement and digitization, 4) identification of in vivo point spread function. Since the Kalman-Bucy filtering approach has already been developed by various investigators for image restoration of the motion blurred, noisy[7], space-variant photographic images[8], the Kalman filtering approach combined with vector scanning process, where several lines of image are scanned at one time, can be applied to solve the above first three problems in ultrasound imaging. Thus, the major remaining problem in applying the present method for clinical measurement is to find a method of estimating in-vivo point spread function from the measured in-vitro PSF and the degraded image itself. Some information on this problem can be obtained in animal experiments by evaluating the reflector located inside the anatomical region.

5. Conclusion

In this paper, a recursive scheme is introduced to improve lateral resolution of the B-scan ultrasonic images blurred by a finite beam width of the transducer. The present method is based on the model of the blurring process by a linear discrete-time dynamic system. The coefficient matrices of these dynamic equations of the blurring process are obtained from the measured point spread function. In a phantom study, two pins located 3mm apart can be separated after recursive processing, while it is difficult to separate in normal B-scan images of preprocessing. In general, the recursive algorithm is faster in computation than Fourier transform method. Also, the zeros do not arise in inverse system, since an exact model operating over a finite picture is utilized. Futhermore since the recursive scheme leads to significant saving in computer memory, it will be useful in the on-line processing of large image arrays.

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