Improvement of Spatial Resolution by Two Directional Scanning for Ultrasound 3D Reconstructions

超音波3次元再構成における2方向スキャンによる分解能向上

Keisuke Yamakawa[1†], Hirozumi Takeshima[1], and Tomohiko Tanaka[1] ([1]Hitachi)
山川 恵介[1†], 竹島 啓純[1], 田中 智彦[1] ([1]日立製作所)

1. Introduction

Minimally invasive surgery (MIS) such as vascular surgery under the guide by X-ray fluoroscope system becomes essential to reduce the patients' burden and increase QoL (Quality of Life). To reduce radiation dose, ultrasound system is used in MIS for some areas such as the lower limb interventions.

However, widespread ultrasound system with a 1-dimensional (1D) probe can only obtain 2D images, and thus, the treatment device and target lesion can be easily lost, because they move to off-plane. To improve the detectability of the device, our group has been developing photoacoustic beacon device, which emits ultrasound from its tip[1]. To improve the lesion detectability, 3D image reconstruction using the data obtained by free hand or visual servoing has been studied. The problem of 3D reconstruction is that resolution along a lateral direction depends on beam width, which varies at different depth as shown in **Fig. 1**. Thus, the spatial resolution obtained by the 1D probe is anisotropic, and the reconstructed image has the insufficient resolution.

The objective of the present study is to improve the spatial resolution of the 3D image obtained by the 1D probe.

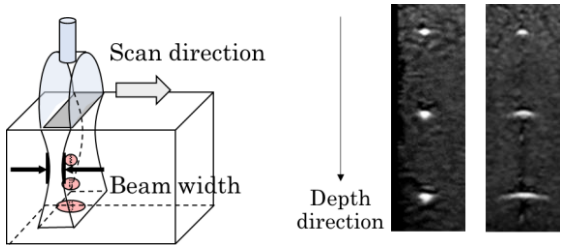


Fig. 1. Ultrasound 3D image system by the 1D probe; (a) Lateal scan direction, (b) Reconstructed 3D image without beam width effect, (c) Reconstructed 3D image with beam width effect.

2. Methods

To improve the spatial resolution of the 3D image, we proposed the combination of two scans with directions perpendicular to each other, as shown in **Fig. 2**. After the position adjustment between the two reconstructed images by using ZNCC (Zero-means Normalized Cross-Correlation)[2] shown Eq. (1), they are added to compensate for the worse resolution in the scanning direction.

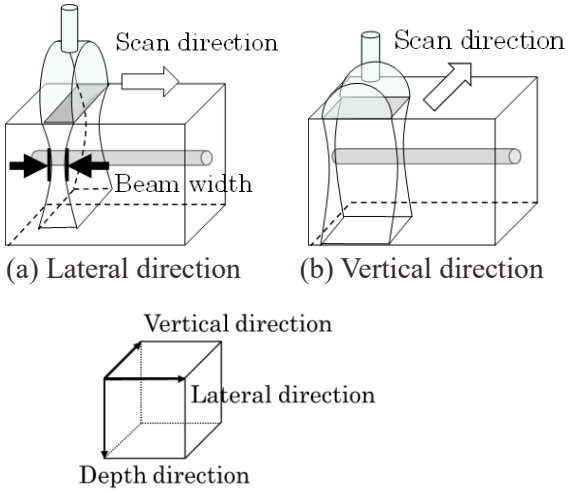


Fig. 2. Two scan directions and 3D direction

$$S_{ZNCC}(d_x, d_y) = \frac{\sum_{i=0}^{I}\sum_{j=0}^{J}\{(g(d_x+i,d_y+j)-\mu_g)(f(i,j)-\mu_f)\}}{\sqrt{\sum_{i=0}^{I}\sum_{j=0}^{J}(g(d_x+i,d_y+j)-\mu_g)^2}\sqrt{\sum_{i=0}^{I}\sum_{j=0}^{J}(f(i,j)-\mu_f)^2}} \cdots (1)$$

To demonstrate the proposed method, measurements of a phantom containing thread-like structures were performed with a motorized stage. An ultrasound equipment (Hitachi, Ltd.) which has the linear probe with frequency range of 2-12 MHz was used. The two conventional methods of lateral or vertical direction scan without combination and the proposed method combining two directional scans were evaluated by using 3D Ultrasound Calibration Phantom ATS (Computerized Imaging Reference Systems, Inc.). The phantom consists of monofilament nylon within urethane rubber to

† keisuke.yamakawa.fd@hitachi.com

evaluate the spatial resolution. The scan and reconstruction conditions are shown in **Table I**.

Table I. Scan and reconstruction conditions

Parameter		Value
Scan	Scan direction	Lateral, Vertical
	Measured data [voxel] (Detector × Depth × position)	Lateral:311 × 720 × 397 Vertical:311 × 720 × 121
	Scan Field of View[mm × mm] (Array × Scan distance)	Lateral:40 × 66.1 Vertical:40 × 20.2
	Scan Pitch [mm/position]	0.167
Recon struction	Voxels [voxel]	511(Lateral) × 720(Depth) × 397(Vertical)
	Voxel size [mm/voxel]	0.13 × 0.11 × 0.13
	Interpolation mode	Bilinear mode
	Registration mode	ZNCC

3. Results and Discussion

The elongation of the image to the scanning direction was significantly improved by the proposed method, as shown in **Fig. 3**. The spatial resolution at the depth of 50 mm from the surface turned out to be 3.3 mm (FWHM), compared with 6.1 mm with the conventional method in the **Fig. 4**. The achieved resolution was also better than the target, about 5.0 mm, which corresponds to the diameter of the lower limb vascular.

The results with the conventional scan of the other direction (vertical) in Fig. 4(a) shows better resolution than the proposed method, which means significant resolution dependence on the direction as described in Introduction. On the other hand, the resolution of the proposed methed is more isotorpic.

The scanning time of the two directions by the proposed method is twice as long as that of the conventional method. It would mean larger target motion due to e.g. breathing, rolling over or heartbeat. To mitigate these motion, some methods like gating, fastening of body or the nonlinear registration methods may be useful.

4. Conclusion

We demonstrated that the spatial resolution of the 3-dimensional image obtained by the 1-dimensional ultrasound probe can be improved by the proposed method, which would contribute to the improvement of the diagnostic accuracy.

References

1. T. Tanaka, R. Imai, T. Takezaki, T. Matsuda and S. Onoe: *SPIE BiOS* (San Francisco, CA, 2018), Proceedings Vol.10494.
2. M. Hashimoto: The 19th Symposium on Sensing via Image Information (Yokohama, Japan, 2013).

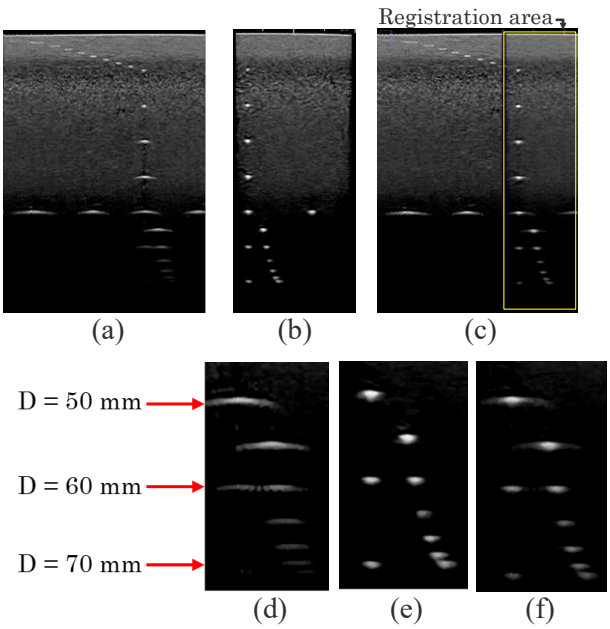
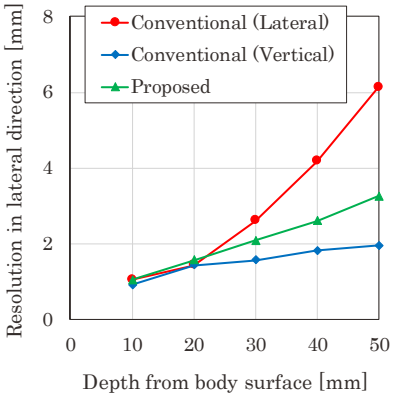
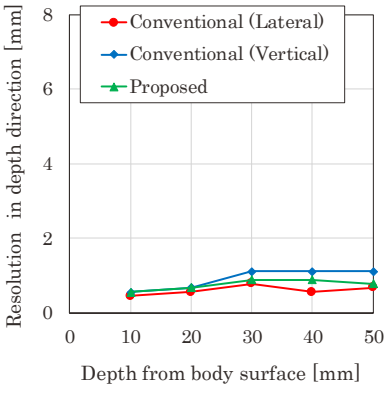


Fig. 3. Reconstructed images and enlargement images obtained with the phantom data (Window Level:25000, Window Width:40000) (a) Lateral scan direction, (b) Vertical scan direction, (c) Combined image with the proposed method, (d) Enlargement of (a), (e) Enlargement of (b), (f) Enlargement of (c)



(a) Resolution in lateral direction



(b) Resolution in depth direction

Fig. 4. Line profiles across the line phantom