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Evaluation of Synthetic Transmit Aperture 3D Acoustic Imaging Using 2D Transmitter Array

Natsuda Laokulrat[1†‡], Yasushige Maeda[2], Masanori Sugimoto[1], and Hiromichi Hashizume[3] ([1]The Univ. of Tokyo, School of Engineering; [2]The Graduate Univ. of Advanced Studies, Dept. of Informatics, School of Multidisciplinary Sciences; [3]NII, Information Systems Architecture Science Research Division)

1. Introduction

The paper describes a 3D acoustic imaging system that uses a 2D receiver array and a 2D transmitter array. For many years, high quality acoustic imaging has been achieved by using synthetic transmit aperture (STA) technique [1][2]. Normally, STA uses an array of receivers and a small number of transmitters to produce an image. However, the conventional arrangement of transmitters in a same horizontal plane or linear array does not provide good signal strength all over scanned target space since directivity of transmitted signals are limited to some particular directions, i.e. directions along the plane of transmitters. As a result, transmitted signals are strong along the plane of transmitters but weak in upper and lower space so it is not suitable for creating 3D images.

In this paper, we observed 3D acoustic imaging results by using a 2D transmitter array and a 2D receiver array. The image reconstruction is based on Time-division Synthetic Transmit Aperture (TD-STA) technique.

2. 3D Acoustic Imaging

STA imaging technique is applied to the imaging system with a 2D receiver array and a 2D transmitter array. First, a received signal at each sensor is cross-correlated with the pre-defined transmitted waveform. The cross-correlation function is given by

$$f_{i,j}(t) = \sum_{l=1}^{L} s(l) r_{i,j}(t+l)$$

where $f_{i,j}(t)$ is a correlation result of a received signal from the sensor at ith row and jth column at time t, $s(l)$ is the transmitted signal, $r_{i,j}(t)$ is a received signal, and L is the length of the transmitted signal.

An image line of a 3D image can be obtained using

$$B_{x,y}(t) = \sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{i=1}^{I} \sum_{j=1}^{J} f_{i,j}(t - d_{x,y,m,n,i,j})$$

where $B_{x,y}(t)$ denotes the value of an image line at xth row and yth column at time t, $d_{x,y,m,n,i,j}$ is the applied delay. M, N, I, J are the number of transmitter rows, transmitter columns, receiver rows, and receiver columns respectively.

The delay values that are applied to the data from each sensor can be calculated by

$$d_{x,y,m,n,i,j} = \frac{|\overrightarrow{Tx}_{m,n} - \vec{F}_{x,y}| + |\overrightarrow{Rx}_{i,j} - \vec{F}_{x,y}| - 2(|\vec{F}_{x,y}|)}{c}$$

where $\overrightarrow{Tx}_{m,n}$ is the position of the transmitter at mth row and nth column, $\overrightarrow{Rx}_{i,j}$ is the position of the receiver at ith row and jth column, $\vec{F}_{x,y}$ is the position of the focal point on the image line at xth row and yth column, and c is the speed of sound.

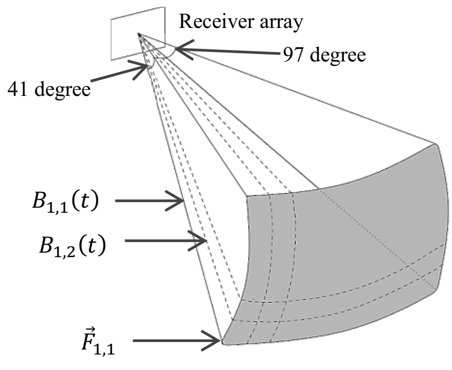

Fig. 1 Scanned target space. The origin point is the center of the receiver array.

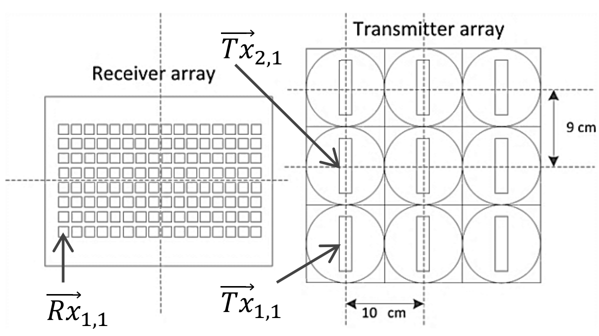

Fig. 2 Arrangement of the receiver array and the transmitter array

natsuda@itl.t.u-tokyo.ac.jp

3. Experiment

We use a 2D array of receivers which is composed of 128 MEM-based ultrasonic microphones aligned in 16x8 planar grids. A 2D transmitter array is simulated by using an ultrasonic transmitter to fire a pre-defined signal at 9 different positions sequentially as shown in the **Fig 2**. A multi-carrier signal is used for transmission and pulse compression. The transmitted signal from each firing is captured and processed in a PC after all transmission events are completed.

The real imaging experiment is done in an indoor environment as shown in **Fig. 3**. The image has 97(horizontal)x41(vertical)-degree field of view with 1-degree angular resolution as shown in **Fig. 1**.

4. Results and Discussion

The image reconstructed by using STA technique is demonstrated and compared with the images that are generated by the conventional beamforming. The reconstructed images using the conventional beamforming method are shown in **Fig. 4 (a)** and **Fig. 4 (b)**. The image from STA imaging is shown in **Fig. 5**. The objects in the conventional beamforming results appear in the same shape. Moreover, in Fig. 4 (a) and Fig. 4 (b), only 2 objects are seen due to the limited field of view of a transmitter. In Fig. 5, all three objects can be seen and the shapes of the objects can be distinguished more obviously.

One of the limitations of the real system is the directivity of the speaker which limits the field of view of the imaging system. Another limitation is the radiation pattern of the speaker. The uneven radiation pattern degrades the resulted image. Besides, the STA imaging system decreases the overall frame rate since it needs many transmissions.

5. Conclusion

3D acoustic imaging using a 2D receiver array and 2D transmitter array is investigated. The result proves that the image reconstruction using STA technique with 2D transmitter array can give high quality 3D images.

6. Future work

The uneven radiation pattern of the transmitter will be analyzed thoroughly and possibly solved by rearranging the positions and arrangement of the elements in the transmitter array in order to achieve a better imaging result.

References

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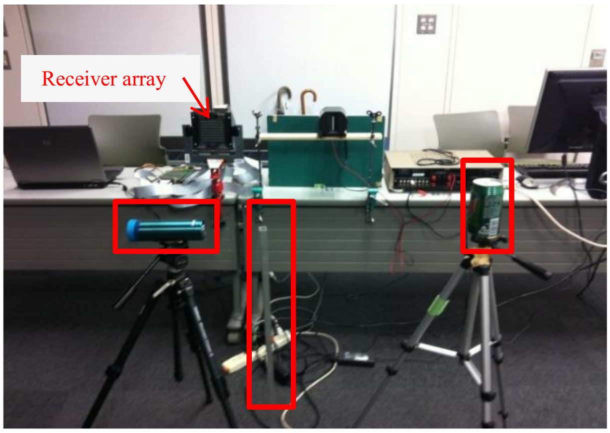
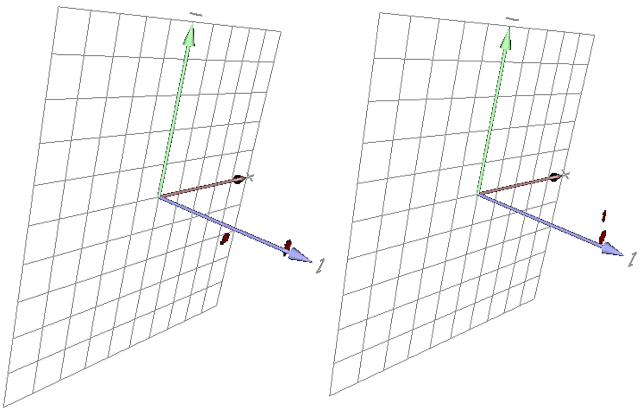


Fig. 3 Real imaging experiment setting. Three objects with different sizes and shapes are placed randomly (red rectangle). The receiver array and the transmitter are fixed on the table.



(a) (b)

Fig. 4 Image from conventional beamforming (a) when $Tx_{1,1}$ is used (b) when $Tx_{2,1}$ is used

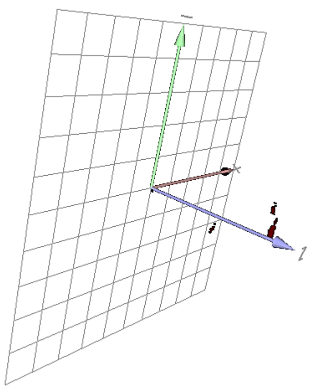


Fig. 5 Image from STA imaging when all 9 transmissions are used