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Single Transducer Ultrasound Imaging by Multiple Elements Reception

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1. Introduction

The application of ultrasound imaging in clinical diagnosis has recently witnessed a surge in growth, largely due to the advantages it offers in terms of radiation-free imaging, cost-effectiveness, and its non-invasive nature. To ensure an accurate diagnosis, the image must have a higher resolution and a greater signal-to-noise ratio (SNR).

At present, ultrasound imaging is conducted through the use of a number of elements that are connected to a complex electrical wiring system. In order to generate the image with such a system, a well-known beamforming technique is employed. A considerable number of researchers have developed methods for enhancing image quality based on sensor array systems.[1,2)]

In the medical field, there is a need for applications and systems with specific features, including a small device and a simple system, for the purpose of administering a particular treatment. Accordingly, the development of a system with a compact and simple structure is imperative. Recently, structured ultrasound microscopy (SUM) was studied by employing a single element with an irregular acoustic lens to create a spatial coding condition.[3)] A physical rotation was carried out for obtaining more measurements in order to increase the image resolution. In a previous study, we proposed the electrode distribution system (EDS)[4)] to avoid a physical movement. The electrodes for transmitting or receiving were controlled by a circuitry system for increasing the number of measurements.

In this study, we propose the use of EDS with grouping of the elements for reception. The set of elements for reception was grouped into two scenarios, namely dense and sparse selection. The beamforming technique was then applied to construct the image.

2. Methods

2.1 Dense and sparse scenario

Figure 1 depicts the proposed model, which groups a number of elements for reception. The elements were selected based on two scenarios, namely sparse and dense, for the purpose of comparing image quality. In the dense scenario, the adjacent element positions were selected for reception, as illustrated in **Fig. 1**(a) for the initial transmission with the same elements for transmission. The measurement was repeated for a subsequent block of elements until all available elements had been covered. By employing the dense scenario for reception, an image with a high intensity can be obtained due to overlapping of target reflections.

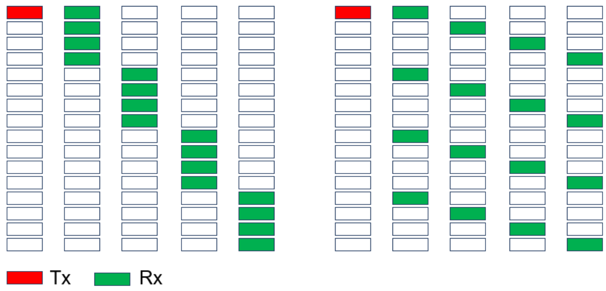

Fig. 1 The elements schema employs a multiplicity of transmissions for reception, encompassing (a) dense and (b) sparse selections.

In the sparse scenario (see **Fig. 1**(b)), there is a certain degree of space between the assigned elements. In general, the sparse scenario has a wider aperture size compared to the dense one. This scenario also allows for the achievement of a high image resolution due to a low overlapping of the reflection from the target.

2.2 Coherence factor

The image was constructed using the beamforming method, whereby the sampling points of the single in-phase quadrature (IQ) signal corresponding to the time travelling from the transmitting points to the reception elements were selected. The coherence factor (CF)[5)] method was applied to compound over the number of sampling points picked up, in order to enhance the ability to remove speckle. This is defined by the following equation:

$$CF = \frac{\left|\sum_{i=1}^{N} x_i\right|^2}{N\sum_{i=1}^{N}|xi|^2} \quad (1)$$

$$Y_O = CF \times \sum_{i=1}^{N} x_i \quad (2)$$

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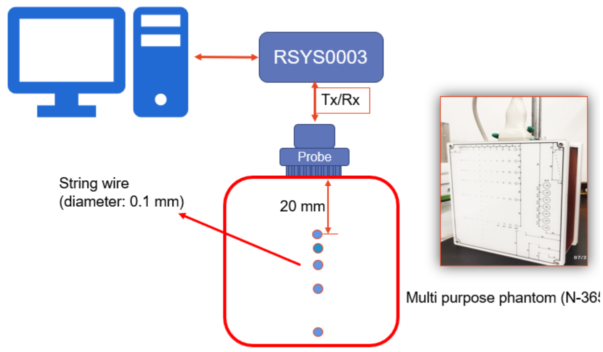

Fig. 2 Experimental condition.

The CF has also been utilized to integrate over a multitude of echo sets and transmissions.

3. Results and discussions

3.1 Experimental conditions

The proposed method was demonstrated using experimental data obtained from an array transducer system, which was modeled as a single element. An experimental platform for medical ultrasound applications (RSYS0003, Microsonic Co., Ltd., Tokyo, Japan) was utilized to perform the transmit and receive sequence with a sampling frequency of 31.25 MHz. The ultrasound transducer employed was a linear array probe (T0-1599, Nihon Dempa Koygo Co., Ltd., Tokyo, Japan), comprising 64 elements (1.2 mm thick and 0.115 mm spacing) that transmitted a short pulse signal with a center frequency of 5.21 MHz. **Figure 2** depicts the experimental conditions utilized in this study.

3.2 Experimental results and discussion

Following the ultrasound measurement, a B-mode image was generated using MATLAB R2022a. The B-mode images, which represent both dense and sparse scenarios, are presented in **Fig. 3**. **Figure 4** illustrates the full width at half maximum (FWHM) at -6 dB of the wire string targets, demonstrating enhanced resolution in sparse scenarios. In addition

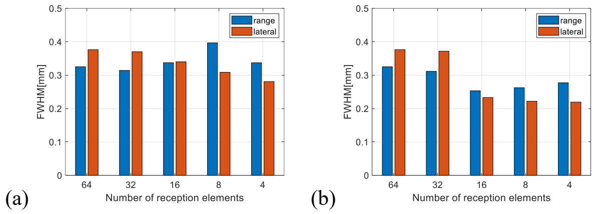

Fig. 4 FWHM of (a) dense and (b) sparse scenario for wire string target.

to wire string targets, the proposed method was evaluated using a cyst target and the human carotid artery, as illustrated in **Fig. 5**. The image with sparse scenario shows superior image resolution. Conversely, the image with a dense scenario demonstrates superior image quality for cyst and carotid artery targets.

4. Conclusions and future works

The B-mode images were successfully constructed based on beamforming in the case of a single-element system. The sparse elements demonstrated superior resolution in terms of range and lateral resolution. However, the B-mode image of the carotid artery with the dense elements exhibited enhanced quality. The cyst target exhibited poor resolution due to the weakness of its backscattered signals.

References

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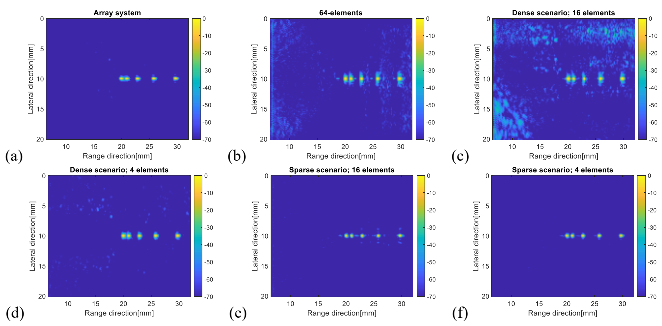

Fig. 3 B-mode images; (a) array system; single system with (b) 64 elements; dense scenario of (c) 16 and (d) 4 elements; sparse scenario with (e) 16 and (f) 4 elements for reception.

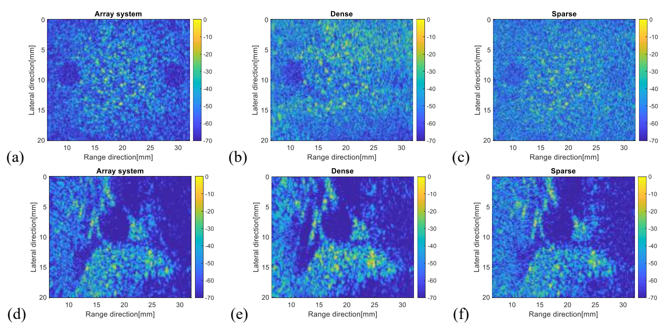

Fig. 5 B-mode images; cyst target with (a) array, proposed model with (b) dense, and (c) sparse scenario; human carotid artery with (d) array, (e) dense, and (f) sparse scenario.