

Ultrasonic Transducers for Medical Volumetric Imaging

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1. Introduction

Three-dimensional (3-D) ultrasound imaging is a new, exciting technology that allows physicians to use ultrasound to view pathology as a volume, thereby enhancing comprehension of patient anatomy. Work on 3-D visualization began in the early 1980's. Some basic methods came from the group at Stanford University [1]. Other work came from cardiologists who made efforts to ascertain the volume of cardiac chambers [2]. In the initial stage of 3-D ultrasound imaging, a 1-D transducer was mounted on an articulated arm where positions of the transducer could be determined by monitoring position sensor signals on the arms. The 1-D array transducer was mechanically moved to provide the 3-D images by sweeping or rotating using either constrained free-hand adapters or an external motion-sensing system. The principle was to stack successive parallel 2-D image sections together with their positional information to compose a 3-D image by a computer [3]. Another group at the Columbia University developed the method for 3-D spatial registration and display of position and orientation of real-time ultrasound images, which led to the mechanical sequential scanning [4]. In obstetrical and gynecological 3-D imaging, mechanical designs using this sequential scanning method are now a pretty popular choice. On the other hand, Smith and his group developed a matrix array transducer that could image cardiac structures in real-time and 3-D [5]. The matrix array transducer reported in 1997 by the team, which steered the ultrasound beam in three dimensions, contained 2,000 elements in which 512 were used for image formation [6]. Due to the relatively small size of the transducer, it was more suited to cardiac examination rather than for the abdomen.

The 3-D ultrasound imaging technology has benefitted from increasingly sophisticated system integration and computer technology. However, much of this progress has been derived from the development of the transducers that are in direct contact with patients. This paper reviews the transducer technology for the 3-D ultrasound imaging with particular emphasis on the operation principle and structure of the mechanical and matrix array transducers.

2. Mechanical transducer

Conventional 1-D array, either linear or curved, transducer can acquire only 2-D images. Mechanical transducers are combining these 2-D images to compose a 3-D image with the information on the position of the 1-D array. Position data may be obtained from an external positioning system in the examination room or stepping motors inside the transducer. There are two different main approaches to obtain a 3-D ultrasound data set. The first approach tracks the motion of an ultrasound transducer in space, which requires external "space-tracking" technology; this method is often referred to as random or free-hand scanning. In this free-hand scanning, a sonographer holds the 1-D array transducer and manipulates it in the usual manner over a target, e.g. human body to be viewed. Multiple 2-D images are acquired at arbitrary positions and angles according to the control of the sonographer. Then all the 2-D images each with corresponding transducer position and angle information are combined and processed to compose a 3-D image. This approach uses a position sensor device attached to the transducer that simultaneously determines the position and orientation of the transducer. The second approach uses internal position sensing devices installed inside the transducer and the transducer motion follows a pre-defined profile, which is named mechanical sequential scanning. As the transducer is moved, 2-D ultrasonic images are collected at predefined spatial intervals so that the imaging sequence acquires the volume of interest without missing any regions. Since the positioning system is implemented within the transducer, the transducer tends to be relatively larger than standard 1-D array transducers, but it eliminates most of the issues related to external position sensors needed for the free-hand scanning with respect to calibration and accuracy. The mechanical sequential scanning system has the capability of controlling a servo or stepping motor that is able to accurately manipulate the position of a transducer. **Fig. 1** is a schematic internal structure of the mechanical sequential scanning transducer. The technical issues concerning higher performance with these transducers are a higher scanning rate (wobbling rate), a larger scanning angle (field of view), and better long-term reliability and compliance.

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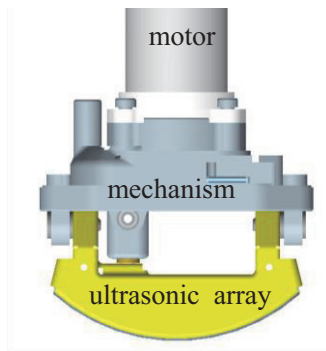


Fig. 1 Schematic internal structure of the mechanical sequential scanning transducer.

3. Matrix array transducer

The ideal, but technically the most challenging, approach to have true real-time 3-D images is the one shown schematically in Fig. 2. The matrix array transducer can be considered a multiple linear connection of 1-D phased array transducers. The 2-D array transducer called matrix array transducer generates a pulse of ultrasound diverging away from the array in a pyramidal shape. After transmission of the sound pulse into a wide-angle cone volume by parallel processing, a multiplicity of receiving sound beams allows sampling the volume at one shot. The integrated images are true real-time 3-D ultrasound images. For high resolution of the 3-D image, a lot of elements are required to be installed in the matrix normally in the order of several thousands compared with several hundreds in conventional 1-D array transducer. Efforts are being continued to further increase the number of the active elements.

Although the ultimate expectation is that this matrix array transducer will replace integrated mechanical scanning transducers and other position-sensing systems, matrix array transducer is still a developing technology. Thus far, 3-D ultrasound imaging systems utilizing matrix array transducers have been used to obtain simultaneous planes from the volume, rather than acquiring the entire volume. A significant issue to be resolved in the electronics side is the data bandwidth required for real-time volume acquisition. Although multiple parallel channels can be used, issues of interference and computing/storage bandwidth still need to be resolved. In the transducer side, the huge number of elements in the matrix array transducer inhibits the use of conventional dicing and wiring technology. Much more fine and precise material processing and fabrication or MEMS technology is essential. In addition, the close spacing between the active elements causes severe cross-coupling between the elements. The cross-talk normally increases in proportion to the number of elements, and the

cross-talk can change the beam pattern and sensitivity of the transducer. In order to reduce the level of the cross-talk, it may be a must to install minor kerfs between the existing major kerfs of the matrix array, which actually quadruples the number of elements to be implemented in the array.

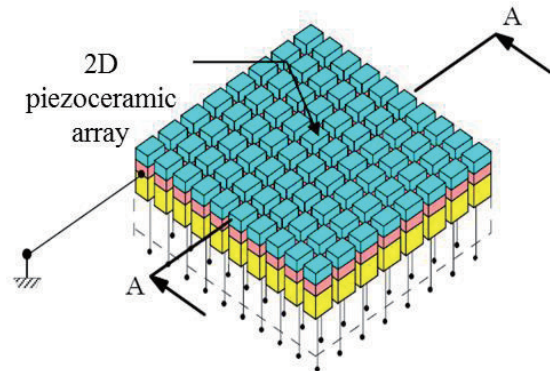


Fig. 2 Schematic internal structure of the matrix array transducer.

4. Conclusions

In this paper, the concept and principle of 3-D ultrasound imaging transducer technology were reviewed by describing mechanical transducers and matrix array transducers. 3-D ultrasound imaging is a new, exciting technology that allows physicians to use ultrasound to view anatomy and pathology as a volume, thereby enhancing comprehension of patient anatomy. Continuing development of transducer technology is playing a key role in enhancing the 3-D imaging performance to replace current 2-D sonography by providing real-time capability and interactivity. It is expected that 3-D ultrasound imaging will be a routine part of patient diagnosis and management in the future.

References

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