ACOUSTICAL IMAGING BY MEANS OF MULTI-FREQUENCY HOLOGRAM MATRIX

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ABSTRACT

A multi-frequency holographic imaging method has been developed, which is an advanced application of the hologram-matrix imaging method suggested and developed by the authors. This new method is based on the idea that axial resolution as well as transverse one can be obtained by properly synthesizing transversely focused beams of different frequencies. This idea has been included into the hologram-matrix imaging method. An image is reconstructed by a linear transformation from hologram matrices of different frequencies. Grating-lobe artifacts usually encountered in the multi-frequency imaging methods are eliminated using nonuniformly spaced frequencies. Thus an imaging of objects placed in the near field by a holographic synthetic aperture method has become practical with a small transducer array and simple electronics.

A design way of transducer arrays and frequency series for this imaging method is introduced in this paper. Three examples of the design are evaluated in their point-spread functions and imaging abilities from simulated hologram matrices of a multi-point object. The transmitter is of one element, the receiver is composed of 31 or 37 elements, and the number of frequencies is 40.

Experimental results also shows that this method is promising. Measurement of the multi-frequency hologram matrices can be done within 30 ms. It may take only few minutes to reconstruct an image of $80 \times 80$ pixels by a high-speed mini-computer.
INTRODUCTION

Since the invention of the HISS radar, various types of imaging methods by means of hologram matrix have been introduced by the authors. Especially two-dimensional acoustical imaging has been investigated theoretically and experimentally. The hologram-matrix imaging method first measures a complex "hologram matrix", each element of which is the complex amplitude of the field detected by a receiver element scattered from an object illuminated by a transmitter element, and then reconstructs images numerically transforming the matrix. In the first type, both transmitter and receiver arrays were placed on a line. The axial resolution was poor.

In the second type, we introduced a method in which a transmitter array and a receiver array were placed in the imaging plane so that their synthesized beams may intersect with each other at right angles at the center of the image region. Experiments showed that this method gives good two-dimensional resolution and a high S/N ratio. It has, however, one demerit that the direct acoustical coupling between the transmitter and the receiver must be excluded by an acoustical absorber placed between them, although the electrical coupling is easily kept away with the electrical shield. This may limit somewhat practical utility of this method.

The third type, multi-frequency method, removes the above difficulties, i.e., poor axial resolution in the first type and necessity of placing an acoustical absorber in the second type. First, we made imaging placing the transmitter and receiver arrays, both of which are composed of 37 elements, on a line as in the first type, but using five different frequencies. The experiment gave images of good resolution and a high S/N ratio. Second, we got an idea that one of the transmitter and receiver arrays in the second type can be replaced by a frequency series. The best way will be a combination of a receiver array, one transmitter element and a frequency series, which makes high-speed measurement of the hologram matrix possible without high voltage- and high speed-switches otherwise necessary for a transmitter array. Experiments of imaging in microwave and acoustical wave based on a similar idea were made independently by Karg et al. One should take caution, however, in the design of the frequency series, because any uniformly spaced frequency series produces periodic ambiguity, just like the grating lobes of antenna array, in the half-infinite axial direction. In this paper, nonuniformly spaced series are suggested and applied to avoid the ambiguity. They give also the minimum point-spread for a given side lobe level with a uniform weight.

Synthetic aperture techniques developed in the microwave and seismology have been applied to the acoustical imaging by Johnson et al. named "synthetic focusing", which uses acoustical pulse. Our