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Improvement of Noise Source Identification by Phase Redundant Acoustical Holography

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ABSTRACT

This paper introduces a new technology, called phase redundant holography, which successfully performs image reconstruction. A two-step procedure is used to perform this task. First, the conventional method is used to obtain the complex amplitude of the reconstructed image and determine the phase of the final reconstruction. Each reconstructed phase is then compared with the final phase and the phase redundancy is multiplied by the reconstructed image. The phase redundancy is related to entropy of a reconstructed point's phase information. The phase entropy is determined by considering both the conventional final image's phase component and the exact opposite one. The resulting image has the same phase as the conventional method, but is different in amplitude. The proposed method, which utilizes a one-dimensional model, exhibits a noticeable improvement in noise source identification.

1. INTRODUCTIION

In an attempt to identify noise sources, numerous acoustical holography methods have been studied and developed [1], [2]. In holography, adding together the complex waves that propagate from the hologram discovers the constituent reconstructed waves. These complex waves usually have a different phase, although the amplitude may be the same. This suggests that every reconstructed image contains redundant phase information content, or in other words, entropy. If this redundancy is regarded as the purity of the reconstructed amplitude, the product of redundancy and the conventional amplitude will represent the net amplitude.

This paper reports the improvements to sound source identification through the use of acoustical holography with reconstructed phase redundancy.

2. PRINCIPLE OF REDUNDANT HOLOGRAPHY

Redundancy is defined as follows.

$$R = 1 - H/H_{max} \quad --- \quad (1),$$

where **H** is the entropy of the phase content and $\mathbf{H_{max}}$ is the maximum possible entropy. For the purposes of this redundant holography study, the entropy **H** at a reconstructed image is defined by the following equation,

$$H = \sum_{i=1}^{n}(-p_i \log_2 p_i) \quad --- \quad (2).$$

Here, $\mathbf{p_i = S_i / (S_i + O_i)}$, **n** is the total number of reconstructed waves, $\mathbf{S_i}$ contains the same phase component as the conventional reconstructed wave, and $\mathbf{O_i}$ contains the phase component opposite to the conventional reconstructed wave.

That is, $\mathbf{S_i}$ and $\mathbf{O_i}$ are respectively defined as follows:

$$\mathbf{S_i = A_s \cos\Delta\phi - (3)}, \quad \mathbf{O_i = A_o |\cos\Delta\phi| - (4)}$$

where $\mathbf{A_s}$ is an arbitrary reconstructed amplitude for

$$\pi/2 < |\Delta\phi|$$

and $\mathbf{A_o}$ is an arbitrary amplitude for

$$\pi/2 < |\Delta\phi| < \pi.$$

Here, $\Delta\phi$ is the phase difference between the arbitrary reconstructed wave and the conventional reconstructed wave. In Fig.1, examples are shown. **A** is an amplitude of the conventional reconstructed wave.

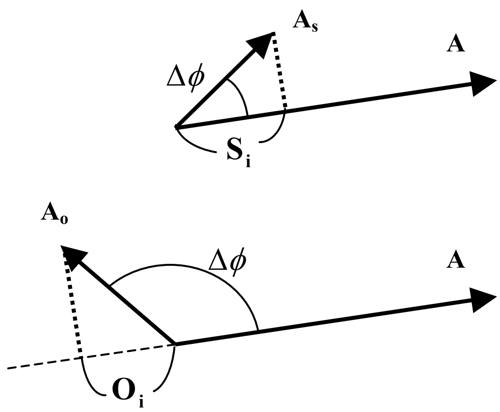

Fig.1 Example concerning the relation between $\mathbf{S_i}$ and $\mathbf{O_i}$.

In redundant holography the net reconstructed wave $\mathbf{V_r}$ is described as the product of redundancy **R** and the conventional wave **V** as follows.

$$\mathbf{V_r = R \cdot V \quad --- \quad (5).}$$

3. ONE-DIMENSIONAL MODEL

Consider the one-dimensional model shown in Fig. 2 that contains two noise sources located at P_1 and P_2. Each source vibrates at different amplitude shown in Table1. Figure 3 shows the conventional reconstructed image. In this figure, the two sources are difficult to distinguish. In Fig. 4, however, the amplitude and phase of the reconstructed complex amplitude at points P_{12} and P_2 differ greatly, even though the conventional value has almost the same amplitude as shown in Fig.3. It is needless to say that P_2 has a exact image point of sound source but P_{12} has no image point. Figure 5 shows the phase entropy H calculated by Equation (1) and Fig. 6 shows the redundant holographic image determined by Equation (5). The two sound sources are sufficiently distinguishable and the lobes around the side of the sound sources are adequately suppressed.

4. CONCLUSION

The proposed phase redundant holography method has not only shown great improvements in resolution, but has also noticeably distinguished the appearance of the side lobes. We may say that this method is an epoch-making technique that could be achieved only after with a computer.

REFERENCES

[1] S. Ueha et al, Optica Acta. **23**, 107-114 (1976)

[2] H. Uchiyama, Proc. of WESTPRC7 vol.4, 1255-1258 (2001)

Table1 Vibration condition in two noise sources

Number of noise sources	2
Sound frequency	4.25kHz(λ=8cm)
Space of noise sources	16cm (2λ)
Distance between noise sources and hologram	z_0 = 120cm(15λ)
Hologram aperture	90cm (11.3λ)
Vibration of noise source P_1	$5\sin\omega t$
Vibration of noise P_2	$4\sin\omega t$

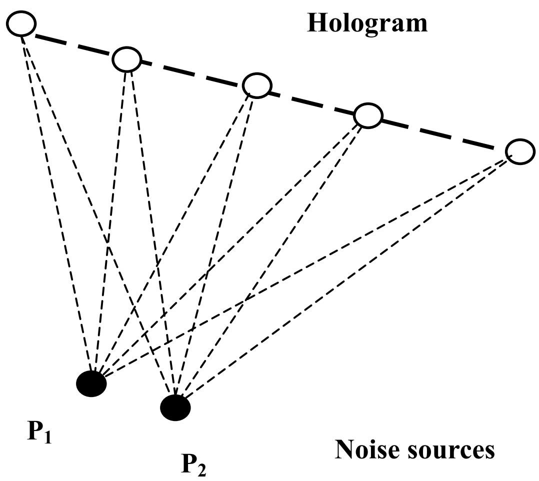

Fig.2 One dimensional model of two noise sources.

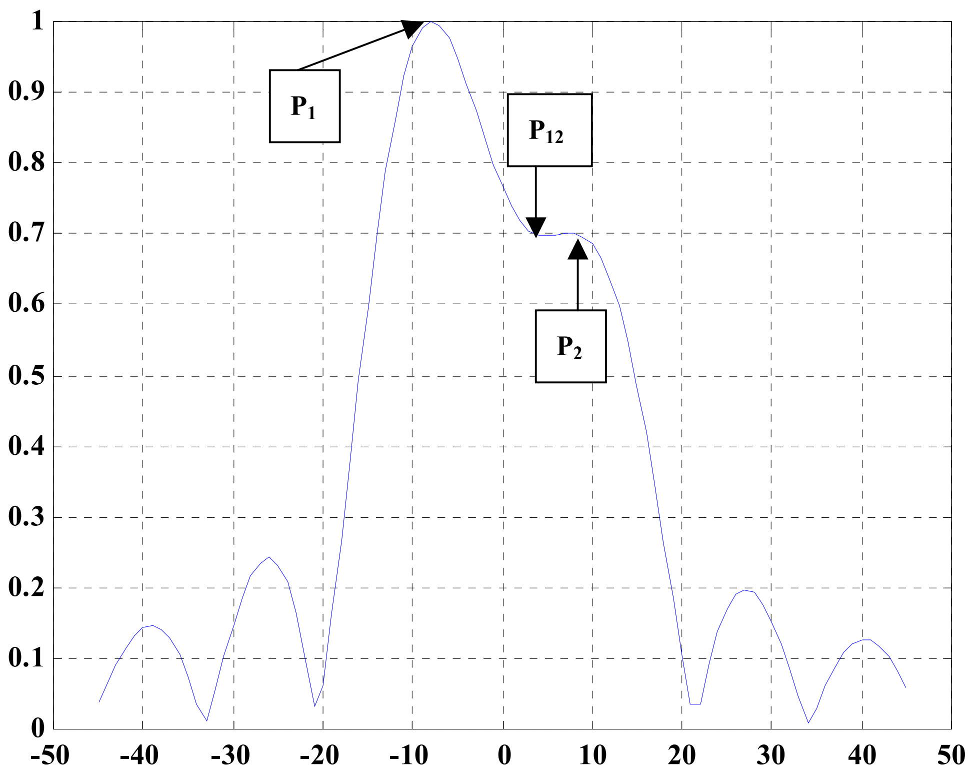

Fig.3 Conventional reconstructed image.

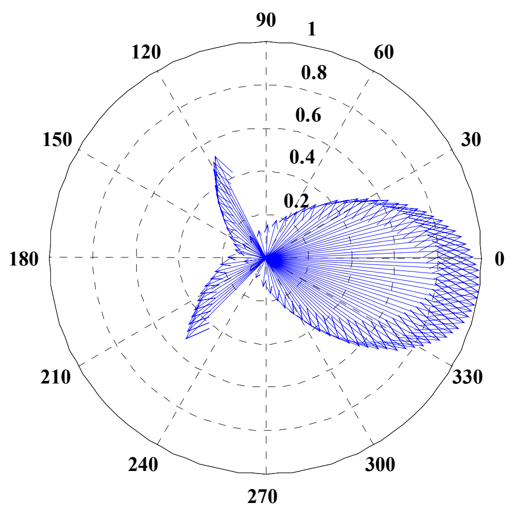

Fig.4 (a) Complex amplitude at point P_{12}.

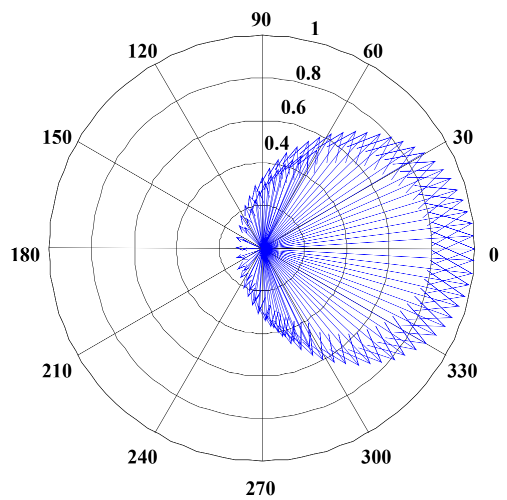

Fig.4 (b) Complex amplitude at point P_2.

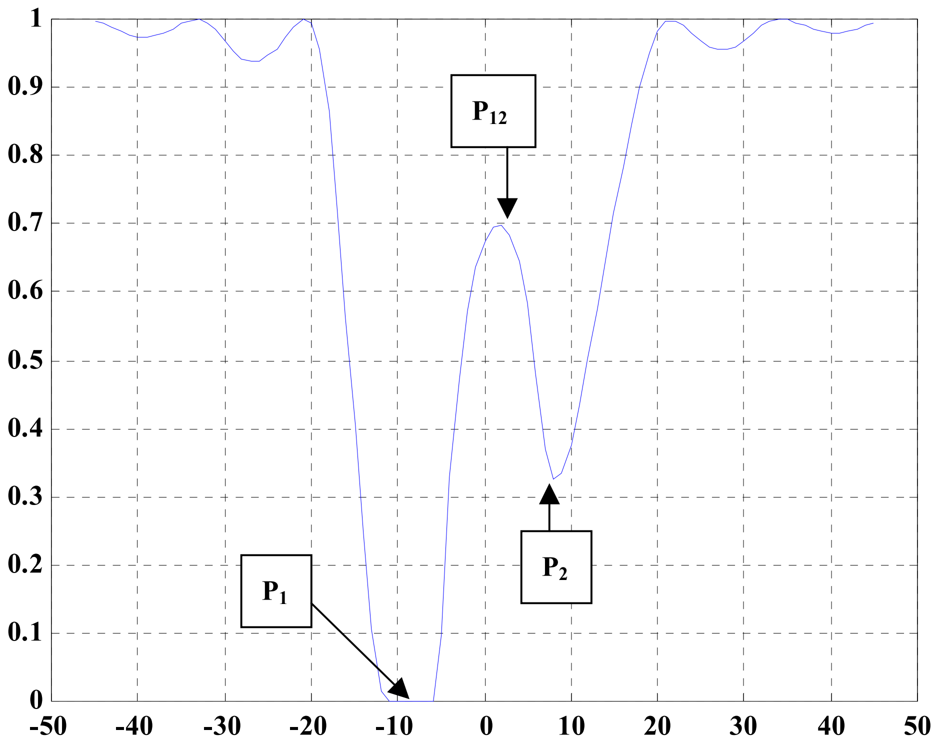

Fig.5 Entropy of reconstructed image.

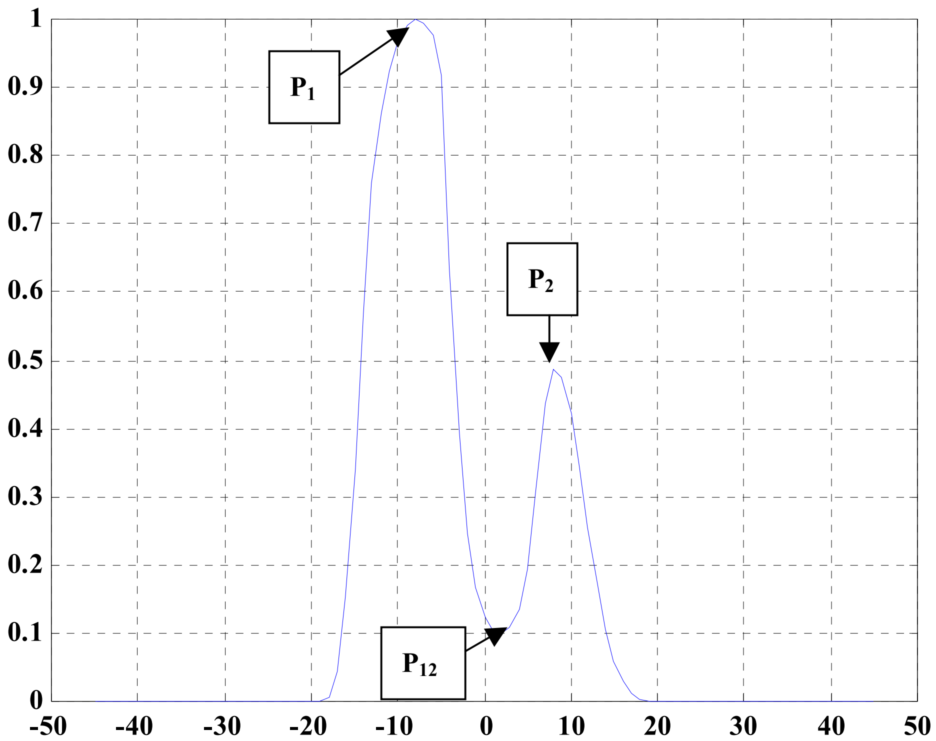

Fig.6 Reconstructed image of redundant holography.