Commun. Comput. Phys. Vol. **28**, No. 1, pp. 1-40
doi: 10.4208/cicp.2020.swsii.review July 2020

REVIEW ARTICLE

Seismic-Wave Scattering, Imaging, and Inversion

Lianjie Huang[1,*], Michael Fehler[2], Yingcai Zheng[3] and Xiao-Bi Xie[4]

[1] *Los Alamos National Laboratory, MS D452, Los Alamos, NM 87545, USA.*
[2] *Massachusetts Institute of Technology, Department of Earth, Atmospheric, & Planetary Sciences, 77 Massachusetts Avenue, Cambridge, MA 02139, USA.*
[3] *University of Houston, Department of Earth & Atmospheric Sciences, Houston, Texas 77004, USA.*
[4] *University of California, Santa Cruz, CA 95064, USA.*

Received 27 April 2020; Accepted 6 May 2020

Abstract. Ru-Shan Wu has made seminal contributions in many research areas in geophysics, such as seismic-wave propagation, scattering, imaging, and inversion. We highlight some of his research in holography imaging, diffraction tomography, seismic-wave scattering and its applications to studying Earth's heterogeneity, one-way wave propagation and one-return wave modeling, beamlet and dreamlet applications, strong non-linear full-waveform inversion, and direct envelop inversion.

AMS subject classifications: 74J05, 74J10, 74J15, 74J20, 74J25, 35C07, 35L05

Key words: Beamlet, diffraction tomography, dreamlet, full-waveform inversion, holography, imaging, one-way, one-return, seismic wave propagation, seismic scattering.

1 Subsurface holographic imaging (1970s–)

In 1970s, Ru-Shan conducted translational research — applying optical holography to subsurface holographic imaging. In optical holography, a hologram is an interference pattern between the scattered light from an object and the reference light. In image reconstruction, the object is re-illuminated by the reference light to reproduce a three-dimensional light field, resulting in an image of the object. Ru-Shan and his colleagues first studied monochromatic (single-frequency) holography for imaging, and found that the main challenge in using elastic or electromagnetic waves for subsurface holographic imaging is its poor longitudinal resolution. To address this limitation, they developed

*Corresponding author. *Email addresses:* ljh@lanl.gov (L. Huang), fehler@mit.edu (M. Fehler), yzheng24@central.uh.edu (Y. Zheng), xxie@ucsc.edu (X.-B. Xie)

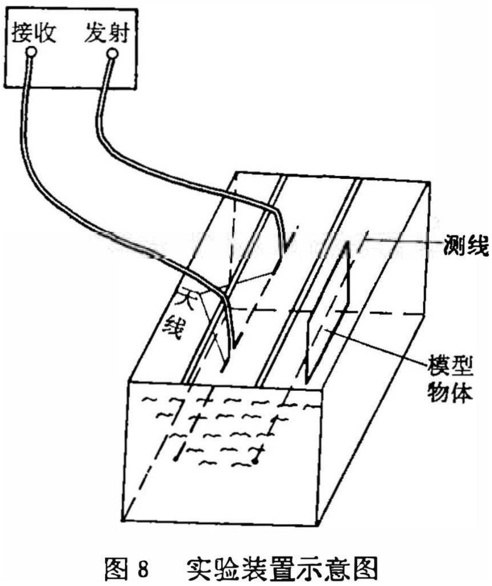

Figure 1: Setup of a water tank experiment for testing multifrequency synthetic detecting holography. (From [60])

the multifrequency synthetic detecting holography to improve the longitudinal image resolution, and published their research results in Chinese with an abstract in English in 1977 [60].

In the multifrequency synthetic detecting holography technique, after obtaining a hologram $H(\omega,\xi,\eta)$ (i.e. data acquisition) for each frequency ω within a given range from ω_1 to ω_2, the multifrequency holography image $M(x,y,z)$ is generated using (see Eq. 8 in [60])

$$M(x,y,z)=\int_{\omega_1}^{\omega_2}\int_{\xi}\int_{\eta}W(\omega)H(\omega,\xi,\eta)e^{-i\frac{\omega}{v}r(\xi,\eta,x,y,z)}d\xi d\eta d\omega, \tag{1.1}$$

where $W(\omega)$ is a weight for a monochromatic hologram at each ω, v is the velocity, and r is the distance from a source to a position (ξ,η) on a hologram via an imaging point (x,y,z).

In Ru-Shan's research on subsurface holographic imaging, he bridged many concepts in different fields: communication and antenna array, correlation functions and matched filters, and phased arrays. In addition, he studied the relationship between multifrequency synthetic detecting holography and "impulse holography," and derived the formulas for longitudinal resolution. He and his colleagues verified the feasibility of their technique using both two-dimensional (2D) synthetic data and laboratory data. They conducted the microwave multifrequency synthetic detecting holography using laboratory data acquired in a water tank (Fig. 1), demonstrating that their method can produce high-resolution and high-quality images. Fig. 2 depicts an image of two aluminum blocks reconstructed using their method with six frequencies.