General Lecture 2 (11:00–12:00, Wednesday, May 29, 2019)

The History and Future of Statistical Electromagnetic Theories and Applications

Speaker: Akira ISHIMARU**,** *University of Washington, Seattle, WA, USA*

Chair: Kazuya Kobayashi, *Chuo University, Tokyo, Japan*

Abstract

Electromagnetic wave theories for deterministic media and boundaries have been extensively studied. In contrast, many natural geophysical and biological media are randomly varying in space and time, for which statistical descriptions and analysis are essential. Examples are remote sensing of geophysical media, imaging of biological media, and bio-optics and ultrasound imaging. These studies often require integration with signal processing. Such applications have become increasingly important in satellite remote sensing and bio-imaging and detection. However, these applications demand development and clear understanding of statistical multiple scattering theories in random media. The fields of waves in random media are interdisciplinary, encompassing geophysics, optics, acoustics, and multiple scattering theories used in astrophysics. This paper attempts to summarize and discuss the key achievements in various areas of electromagnetic theories of random media and applications, and point to possible future developments.

In the middle of the twentieth century, there was increased research of wave propagation and scattering in turbulence and turbid media. Foldy, Lax, Twersky, and Keller performed several fundamental studies to develop basic formulations of coherent and incoherent waves in random media. Tatarskii, Bremmer, Rytov, and Kravtsov made several major contributions, including the path integral. Multiple scattering in random media is closely related to astrophysical problems such as the Dyson and Bethe-Salpeter equations, and the Feynman diagram, as shown in Frisch. It should also be noted that extensive use of the Kolmogorov spectrum of turbulence (Tatarskii) resulted in closer agreement with experimental work. Multiple scattering theories are essential for geophysical imaging (van Zyl, Zebker, Elachi, Ulaby, Tsang, Kong, Fung).

Radiative transfer has been used extensively for bio-imaging. It is important to understand the difference between optical and ultrasound imaging in bio-materials. Tissues offer much scattering and small absorption for optics. Thus, optical beams incident upon tissues are scattered and mostly diffused, and diffusion theory applies. Ultrasound waves, on the other hand, are mostly absorbing in tissues and the first order scattering is dominant.

In the past, communication and propagation through a random medium were treated mostly separately. Communication is studied with some assumptions about propagation, and propagation is studied without much consideration of communication problems. However, recently there has been much interest in combining these two areas (Andersen). A key to this is how to include wave propagation in communications and specifically, how to include the "Mutual Coherence Function" (MCF) in communications theory.

It is conventionally assumed that coherence will be diminished and tend to disappear in backscattering from a random medium. In recent years, however, surprising coherence effects have been observed in multiple scattering. Backscattering enhancement, also called coherent backscattering, appears as a sharp peak in the backscattering, indicating a coherent addition of the scattered waves from a random medium.

Seismic waves in homogeneous earth have been extensively studied (Achenbach, Cagniard, deHoop). However, the earth is heterogenous (random medium) and the effects of a random medium on seismic waves appears as an incoherent wave train, called the coda. Recently, these coda waves have attracted increasing attention (Sato, Fehler, and Maeda).

Several imaging techniques have been applied to imaging through random media, including Time-reversal and MUSIC (Multiple signal classification). They include integration of signal processing techniques and scattering techniques (Fink, Prada, Devaney, Yavuz, Teixeira, Papanicolaou). Time-reversal imaging, MUSIC, DORT (decomposition of time-reversal operator), and SVD (singular value decomposition) have been applied to imaging through random media (Ishimaru) showing superresolution, shower curtain effects, and backscattering enhancement (Prada-Fink, Devaney).

Profile

Akira Ishimaru received the B.S. degree from the University of Tokyo, Tokyo, Japan in 1951 and the Ph.D. degree in electrical engineering from the University of Washington, Seattle, in 1958.

From 1951 to 1952, he was with the Electrotechnical Laboratory, Tanashi, Tokyo, and in 1956, he was with Bell Laboratories, Holmdel, NJ. In 1958, he joined the faculty of the Department of Electrical Engineering, University of Washington, where he was a Professor of electrical engineering, and an Adjunct Professor of applied mathematics. He is currently Professor Emeritus there. He has also been a Visiting Associate Professor at the University of California, Berkeley. His current research includes waves in random media, remote sensing, object detection, and imaging in clutter environment, inverse problems, millimeter wave, optical propagation and scattering in the atmosphere and the terrain, rough surface scattering, and optical diffusion in tissues. He is the author of *Wave Propagation And Scattering In Random Media* (New York: Academic, 1978; IEEE-Oxford University Press classic reissue, 1997) and *Electromagnetic Wave Propagation, Radiation, and Scattering* (Englewood Cliffs, NJ; Prentice Hall, 1991; second edition, IEEE-Press Wiley, 2017). He was Editor (1979-1983) of *Radio Science* and Founding Editor of *Waves In Random Media* (Institute of Physics, U.K.), and *Waves In Random And Complex Media* (Taylor and Francis, U.K.).

Dr. Ishimaru has served as a member-at-large of the U.S. National Committee (USNC) and was chairman (1985-87) of Commission B of the USNC/International Union of Radio Science. He is a Fellow of the IEEE, the Optical Society of America, the Acoustical Society of America and the Institute of Physics, U.K. He was the recipient of the 1968 IEEE Region VI Achievement Award and the IEEE Centennial Medal in 1984.He was appointed as Boeing Martin Professor in the College of Engineering in 1993. In 1995 he was awarded the Distinguished Achievement Award from the IEEE Antennas and Propagation Society. He was elected to the National Academy of Engineering in 1996. In 1998, he was awarded the Distinguished Achievement Award from the IEEE Geoscience and Remote Sensing Society. He is the recipient of the 1998 IEEE Heinrich Hertz Medal and the 1999 URSI Dellinger Gold Medal. In 2000, he received the IEEE Third Millennium Medal.

.