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Computational Electromagnetics: Past, Present, and Future

by
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Abstract

Electromagnetics and Maxwell's equations have been instrumental in the conception of many electrical engineering technologies. It the beginning, it was telegraphy, and rotating machineries. Over the years, electromagnetics has given rise to numerous technologies like wireless communications, antennas, radar, and masers. On the optics side, simplified ray optics theory was used to design lenses and focusing systems.

As many optical systems can be described by ray optics approximations, the first area that requires the full solution of Maxwell's equations is in microwave engineering, antenna design, and remote and subsurface sensing. Hence, there were pressing needs to design better antenna systems for communication, radar for target identification, and radio waves for remote sensing. While closed form solutions offered some physics insight, approximate solutions were invoked to further expand the insight of designers and engineers. When approximation solutions were exhausted, numerical methods or computational electromagnetics (CEM) were developed to further aid designers and engineers.

As demand for numerical methods looms, fast and efficient methods of solving Maxwell's equations become a popular topic of research. There are essentially two classes of solvers for Maxwell's equations: differential equation solvers and integral equation solvers. While differential equation solvers use more unknowns than integral equation solvers, they are easy to implement and to maintain.

Integral equation solvers, on the other hand, use fewer unknowns, but are more difficult to implement. They also yield dense matrix systems that are expensive to solve and store. However, the advent of fast solvers has greatly expedited their solution efficiency. As of this point, dense matrix systems with over three billion unknowns have been solved using fast solvers. Also, the path to large scale computing requires the use of iterative solvers.

Over time, as the demand for CEM solvers grows, more complex structures with a disproportionate number of unknowns need to be solved. They give rise to ill-conditioned matrix systems. Hence, preconditioners or domain decomposition methods are designed to reduce the ill conditioning of matrix system. The preconditioners will greatly expedite iterative solutions to these problems.

Maxwell's equations are also intimately related to mathematical geometry and to quantum physics. Differential geometry concepts can be invoked to help in the selection of basis and testing functions in finding the matrix representations of Maxwell operators. Furthermore, even when quantum theory is invoked in the quantization of electromagnetic fields, the fields are still governed by Maxwell's equations. Therefore, solutions of Maxwell's equations are needed even in the quantum regime. Since photons play an important role in the manipulation of quantum information, the solutions of Maxwell's equations will be instrumental even in quantum optics or quantum electromagnetics. They will play an important role in the area of quantum computers and quantum information.

Biography

Weng Cho Chew received the B.S.E.E., M.S.E.E. and Engineer's degrees and Ph.D.E.E. degree in 1976, 1978, and 1980, respectively, from MIT. He joined the U of Illinois in 1985.

He served as the Dean of Engineering at Hong Kong U (2007-2011). Before 1985, he was a department manager and a program leader at Schlumberger-Doll Research (1981-1985). He served on the IEEE Adcom for AP Society as well as GRS Society. He is active with various journals and societies.

His research interests are in wave physics and mathematics of inhomogeneous media for sensing applications, IC, and antenna applications, as well as fast algorithms for scattering and radiation problems. He originated several fast algorithms for electromagnetics scattering and inverse problems. His research group solved dense matrices with tens of millions of unknowns first ever for scattering problems. His recent interest is in multi-physics phenomena in nano-eletronics and N/MEMS.

He authored and co-authored books entitled Waves and Fields in Inhomogeneous Media, Fast and Efficient Methods in Computational Electromagnetics, and Integral Equation Methods for Electromagnetic and Elastic Waves, and over 350 journal publications, 400 conference publications and ten book chapters.

He is a Fellow of IEEE, OSA, IOP, EMA, HKIE, and was an NSF Presidential Young Investigator (USA). He received the Schelkunoff Best Paper Award for AP Transaction, IEEE Graduate Teaching Award, UIUC Campus Wide Teaching Award, and IBM Faculty Awards. He was a Founder Professor of the College of Engineering (2000-2005), and the First Y.T. Lo Chair Professor (2005-2009), and an IEEE Distinguished Lecturer (2005-2007), Cheng Tsang Man Visiting Professor at NTU in Singapore (2006). In 2002, ISI Citation elected him to be among the Most Highly Cited Authors. He received the AP-Society Chen-To Tai Distinguished Educator Award (2008), and was on the BoD of Applied Science Technology Research Institute, Hong Kong. He is currently the Editor-in-Chief of PIER journals, and the Chair of the IEEE Joint Chapter on AP Society, GRS Society, and Photonic Society, which hosts a seminar series. Recently, he has been elected to the US National Academy of Engineering.