AI and Machine Learning in Design Optimization: Emerging Developments

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Abstract

Developments in machine learning and artificial intelligence have been adapted in Multidisciplinary Design Optimization (MDO) to model complex design problems involving multiple interacting disciplines, identify and capture trends in numerically or experimentally generated data, and address computational challenges associated with multidisciplinary analysis and optimization. This paper provides an overview of these developments over the past several years, starting with the use of fully connected backpropagation (BP) neural networks to model system responses more than three decades ago. Advances in hardware and new computational paradigms have significantly accelerated the pace of these developments, leading to the proposal of many novel applications. Building on early work with BP networks, deep learning has been used to create surrogate models that approximate expensive simulations involving many design features, enabling the rapid evaluation of design alternatives. Generative Adversarial Neural Networks (GANN) have been deployed to create feasible design alternatives, promoting convergence in the design process, while Physics-Informed Neural Networks (PINN) have offered efficiency in modeling data-sparse environments. The use of evolutionary algorithms, Bayesian optimization, and reinforcement learning has enhanced the optimization process, while data-driven approaches have helped identify patterns of system behavior and focus the search on promising regions of the design space. Other approaches, such as active learning, real-time optimization, and transfer learning, have shown promise in improving the efficiency of the design process. This paper reviews specific applications of these developments and discusses how machine learning will facilitate future collaboration across disciplines by integrating data, automating decision support, and improving overall design workflows.

Bio

Prabhat Hajela is the Edward P. Hamilton Professor of Aerospace Engineering, He received an undergraduate degree in Aeronautical Engineering from the Indian Institute of Technology, Kanpur, and his graduate degrees from Iowa State University (MS in Aerospace Engineering) and Stanford University (MS in Mechanical Engineering & Ph.D. in Aeronautics and Astronautics). He was a postdoctoral research fellow at the University of California, Los Angeles.

His research interests are at the intersection of multidisciplinary system design optimization and emergent computing approaches including evolutionary computing and machine learning. The work focuses on the effective integration of knowledge from diverse domains to create efficient and computationally tractable approaches to complex system analysis and design in the presence of uncertainties. Neural networks and machine learning are important computational tools for design space exploration and decision making in such an environment. Ongoing investigations into heuristic computing techniques such as genetic algorithms and immune network modeling promise new and innovative problem-solving paradigms inspired by natural systems. These interdisciplinary approaches hold potential to drive advancements in engineering design and computational intelligence.

Hajela has conducted research at NASA's Langley and Glenn Research Centers, the Eglin Air Force Armament Laboratory, and as the Boeing-A.D. Welliver Fellow at the Boeing Company in 1995. He has authored over 300 papers and articles and co-authored/edited 4 books on structural and multidisciplinary optimization. A recipient of the AIAA's Biennial Multidisciplinary Design Optimization Award in 2004, Hajela is a Fellow of AIAA, ASME, and AeSI.

Hajela previously served as Provost and Chief Academic Officer at Rensselaer Polytechnic Institute and as Vice Provost & Dean of Undergraduate Education. He also served as Administrative Dean of the School of Humanities, Arts, and Social Sciences at Rensselaer.

Dr. Hajela is a past Vice-President of the International Society of Structural & Multidisciplinary Optimization. He has also a past Chair of ASME's Aerospace Division, an organization that serves over 10,000 ASME members with interest in Aerospace Engineering. In 2003, he served as a Congressional Fellow responsible for Science and Technology Policy in the Office of US Senator Conrad Burns (R-MT). He worked on several legislative issues related to aerospace and telecommunications policy, including the crafting of the anti-SPAM legislation (CAN-SPAM) that was signed into law in December 2003. Hajela has served on National Academies Panels related to Aerospace and Aviation research, including the first Decadal Survey of Aeronautics and a review of Aeronautics Research Programs at NASA. He is the former Chair of the NRC Panel on Information Sciences research at the Army Research Laboratory and currently Chairs the NRC Technical Assessment Board for the Army Research Laboratory.

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