Lecture Notes in Mechanical Engineering

Niraj Kumar · Szalay Tibor ·
Rahul Sindhwani · Jaesun Lee ·
Priyank Srivastava *Editors*

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Preface

This unique and important book presents the concept of interdisciplinary research and offers a timely guide for researchers, professionals from both academia and industry and scientists based on the Second International Conference on Future Learning Aspects of Mechanical Engineering (FLAME 2020), held on August 05–07, 2020, Amity University, Noida, Uttar Pradesh, India. The book presents a selected collection of cutting-edge research articles in interdisciplinary areas such as renewable and green energy, automobile engineering, nano and microelectromechanical systems, ergonomics, navigation and sensor networks, acoustics, biomedical and medical devices, nuclear engineering, agriculture engineering, and farm machineries. This book also provides a snapshot of cutting-edge technologies through practical and theoretical investigations and aims to provide a feasible solution to the challenges faced by the society covering a wide range of topics.

The conference (FLAME 2020) has successfully achieved its aims as it laid a platform for academicians, scientists, and researchers across the globe to share their scientific ideas and vision. This conference also provided opportunities for collaborative research for the benefit of mankind. During the 3 days of the conference, many new ideas pertaining to most recent cutting-edge discoveries were presented and exchanged among 550 participants across the globe.

We take this opportunity to acknowledge the sincere efforts of all authors and the publisher. In addition, we express our gratitude to the Department of Science and Technology (DST), Government of India, Siemens, India, and Begell House. Finally, we would also like to express our gratitude to our Respected Founder President, Amity University, Dr. Ashok K. Chauhan, without his blessings, it would have been impossible to complete this book.

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Dr. Szalay Tibor is working as an associate professor and heading the Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics (BUTE), Hungary. He was Vice Dean of Scientific and International Affairs in BUTE, Hungary from 2008 to 2012. He completed Ph.D. in 2001 from BUTE Hungary. He received Gillemot Prize of the BME Faculty of Mechanical Engineering in 2016, Knight-of-Cross from the Order of Merit of the Hungarian Republic in 2015, Békésy Professor Fellowship of the Hungarian Ministry of Education in 2003, Bolyai Research Followship of the Hungarian Academy of Sciences, 1996, Development of technology—reward of the Scientific Society of Mechanical Engineering in 1996 and Scholarship of the Hungarian Academy of Sciences from 1983 to 1986. He was the Hungarian coordinator of two EU FP6 projects and he is responsible for the participation of the BME in the

H2020 Teaming project Center of Excellence Production Informatics and Control (EPIC). He is leading more than 34 research projects and 37 industrial R&D projects. He has supervised 18 students for Scientific Students Work, 143 students for B.Sc. and M.Sc. theses and 6 Ph.D. students. Dr. Szalay has published and presented more than 150 papers.

Dr. Rahul Sindhwani received his Ph.D. degree in Mechanical Engineering (Industrial Engineering & Management) in 2017, M.Tech. degree in Mechanical Engineering (Industrial Engineering & Management) with distinction and Gold Medal in 2010, B.Tech. degree in Mechanical Engineering in 2008, from Kurukshetra University, India. Currently, he is an Assistant Professor in the Mechanical Engineering Department, Amity School of Engineering and Technology, Amity University, Noida, India. He is an active lifetime member of the Indian Society of Technical Education and a fellow member of the Institution of Engineering and Technology. He is having teaching, research, and administrative experience of more than 10 years. He has been actively involved in organizing several national and international conferences and has published more than 25 research papers and book chapters in the area of industrial engineering and management in various international journals of repute. His area of expertise is industrial engineering and management, supply chain management, lean, green and agile manufacturing system along with analysis of problems using structural equation modelling, statistical analysis, interpretive structural modelling, and multi-criteria decision modelling, etc.

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Dr. Priyank Srivastava is Ph.D. from National Institute of Technology Kurukshetra and faculty at ASET, AUUP, Noida. He has completed graduation in 2001, post-graduation in 2006, from Amravati University and Madan Mohan Malviya Engineering College, Gorakhpur, respectively. He has teaching experience of more than 15 years. He has published around 27 papers in international journals, international conferences, and book chapters. His research interests are in the areas of risk and reliability, manufacturing system modelling, maintenance management, operations management, and MCDM techniques.

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SIMP-Based Structural Topology Optimization Using Unstructured Mesh on GPU

Shashi Kant Ratnakar, Subhajit Sanfui, and Deepak Sharma

Abstract Structural topology optimization is a method of finding optimum material distribution within a given design domain, which is subjected to various loading and support conditions. However, the large computation time is one of the major challenges in its implementation. This challenge gets escalated with the use of unstructured mesh. In this paper, a Solid Isotropic Material with Penalization (SIMP)-based implementation of topology optimization on the graphics processing unit (GPU) for a 3D unstructured mesh is presented. The finite element analysis is performed entirely on a GPU. The main implementation challenges are addressed by developing an efficient and optimized GPU *kernel*. The performance of the implementation is analyzed over an example using three different mesh sizes. Results show almost 4× speedup over a standard CPU implementation.

Keywords Topology optimization · SIMP · GPU · Unstructured mesh

1 Introduction

Topology optimization is a method for designing lightweight and reliable structures. Its main objective is to find an optimum layout by distributing material in a given design space. The material is distributed in order to achieve the best structural performance in terms of minimizing compliance, cost, or weight of the structure. The topology optimization has been successfully used in mechanical structural design [1], civil structures [2], aerospace structures [3], to name a few.

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The theoretical aspect of topology optimization is well established. The density-based methods are popular and widely used, particularly SIMP [4]. The density-based methods work on a fixed domain of finite elements and represent a smooth and differentiable problem, which can be solved efficiently by available numerical optimization algorithms.

The SIMP-based topology optimization method begins with the discretization of a design domain, which is known as meshing. In the literature, the structured mesh has been mostly used for meshing solid structures [5]. Structured meshes indeed offer a clear advantage in terms of simplicity of computational implementation, and the amount of computation required. However, their use is limited to simple design problems with regular domain geometry, thereby making their limit applications for real-world problems.

The unstructured meshes are more versatile to discretize domains with complex and irregular geometries. This makes them useful over a wider range of problems, such as those containing nonorthogonal domains and curved boundaries. However, the main challenge is a higher computation time than that with a structured mesh. As topology optimization is already a computationally expensive method, its implementation using unstructured meshes makes it even more computationally challenging.

A viable solution to a high computation time can be found by performing the computation in parallel. The GPU has been very popular in recent years for solving data-parallel computation.

Previous studies used GPU to speedup different parts of topology optimization. The majority of these studies targeted the finite element analysis (FEA) part of the SIMP-based topology optimization [6–8]. Schmidt et al. used GPU to accelerate FEA and gradient computation on a 3D structured mesh. Special attention was given for implementing a sparse matrix–vector product (SpMV) on GPU [5]. Several studies in the literature also computed both FEA and optimization on GPU [9–11]. Methods other than SIMP have also been used with GPU. For example, the level-set method [12] and evolutionary optimization [13] have also been implemented on GPU. Recently, Kiran et al. [14] presented a GPU-based strategy for the generation of finite element stiffness matrices and their assembly. Sanfui et al. [15] used the GPU to accelerate the elemental computation and assembly by exploiting the symmetry. Kiran et al. [16] presented a comparative analysis of the GPU-based solver libraries for a sparse linear system of equations.

Most of the studies discussed above use structured meshes for discretization and analysis. The first work on GPU-based topology optimization using 2D unstructured meshes was presented by Zegard et al. [9]. Later, Duarte et al. [7] presented a GPU-based topology optimization tool PolyTop^{++} using a polygonal mesh. The following are the contributions of this paper.

- Implementation of SIMP-based topology optimization using 3D unstructured mesh on GPU. The implementation is developed using compute unified device architecture (CUDA), to be run on NVIDIA GPUs.