

SpringerBriefs in Applied Sciences and Technology

Computational Mechanics

For further volumes:
<http://www.springer.com/series/8886>

Ramón Quiza · Omar López-Armas
J. Paulo Davim

Hybrid Modeling and Optimization of Manufacturing

Combining Artificial Intelligence
and Finite Element Method

Ramón Quiza
Department of Mechanical Engineering
University of Matanzas
Autopista a Varadero
44740 Matanzas
Cuba

J. Paulo Davim
Department of Mechanical Engineering
University of Aveiro
Campus Santiago
3810-193 Aveiro
Portugal

Omar López-Armas
Department of Mechanical Engineering
University of Matanzas
Autopista a Varadero, km 3½
44740 Matanzas
Cuba

ISSN 2191-5342
ISBN 978-3-642-28084-9
DOI 10.1007/978-3-642-28085-6
Springer Heidelberg New York Dordrecht London

e-ISSN 2191-5350
e-ISBN 978-3-642-28085-6

Library of Congress Control Number: 2012931420

© The Author(s) 2012

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Neither the finite element method nor the artificial intelligence are new tools in modeling and optimization of manufacturing processes. A big amount of information on these topics can be found in the specialized literature. Nevertheless, the combination of both approaches is not as old and widespread. Only in recent years, this approach is beginning to receive a noticeable attention from the research community.

Combining the capability of the finite element method for computing good approximate solutions of partial differential equations defined on geometrically complicated domains with the advantages of artificial intelligence-based techniques for mapping nonlinear noisy relationships and for obtaining near-optimal solutions in complex problems, results in a more powerful and flexible tool. This hybrid approach has been used for solving some problems in manufacturing modeling and optimization, but it is currently in its birth. It can be undoubtedly expected that, in the next years, the growing of the processing power of computers together with the development of new more efficient methods in both areas, increase the efficacy and efficiency of this methodology.

The main objective of this text is to expose some conceptual ideas on the integration of the finite element method and artificial intelligence tool for solving modeling and optimization problems in the field of manufacturing processes. Also, the main topics on both tools are explained and an illustrative sample of the use of the hybrid approach is presented.

The book is directed to the research community dedicated to the mathematical modeling and optimization of manufacturing processes. It is intended to be employed at postgraduate level but some of its topics can be used also in undergraduate courses.

As in every work, the contribution of many people played an important role. However, we want to highlight the support of our college Professor Marcelino

Rivas, through all the processes of conceiving and writing of the book. His advises and suggestions were actually invaluable for this work.

R. Quiza
O. López-Armas
J. P. Davim

Contents

| | | |
|----------|---|----|
| 1 | Introduction | 1 |
| 1.1 | Relevance and Convenience of Hybrid Modeling and Optimization of Manufacturing Processes | 1 |
| 1.2 | Approaches for Combining AI and FEM | 4 |
| 1.2.1 | FEM/AI Models | 4 |
| 1.2.2 | AI/FEM Models | 5 |
| 1.2.3 | Hybrid Approaches for Optimization | 6 |
| 1.2.4 | Fuzzy FEM | 8 |
| | References | 9 |
| 2 | Finite Element in Manufacturing Processes | 13 |
| 2.1 | Basis of the Finite Element Method | 13 |
| 2.2 | FEM for Linear Elastostatic Problems | 16 |
| 2.3 | FEM for Plasticity | 20 |
| 2.3.1 | Plasticity Fundamentals | 20 |
| 2.3.2 | Material Behavior Models | 21 |
| 2.3.3 | Yielding Criteria | 24 |
| 2.3.4 | Governing Equations | 24 |
| 2.3.5 | FEM Formulation | 29 |
| 2.4 | Thermal Analysis | 30 |
| 2.5 | Friction Models | 31 |
| 2.6 | Fracture | 33 |
| | References | 36 |
| 3 | Artificial Intelligence Tools | 39 |
| 3.1 | Preliminary Concepts | 39 |
| 3.2 | Artificial Neural Networks | 40 |
| 3.2.1 | Biological Foundations and Neuron Model | 40 |
| 3.2.2 | Network Topology and Learning | 41 |
| 3.2.3 | Multilayer Perceptron | 43 |

| | | |
|----------|---|-----------|
| 3.2.4 | Radial Basis Function Networks | 46 |
| 3.2.5 | Hopfield Networks | 49 |
| 3.2.6 | Adaptive Resonance Theory and Self-Organizing Maps | 51 |
| 3.2.7 | Warnings and Shortcomings in the Use of Neural Networks. | 56 |
| 3.3 | Fuzzy Logic | 58 |
| 3.4 | Neuro-Fuzzy Systems. | 61 |
| 3.5 | Metaheuristic Optimization | 64 |
| 3.5.1 | Optimization Basis | 64 |
| 3.5.2 | Evolutionary Computation | 66 |
| 3.5.3 | Evolutionary Multi-Objective Optimization | 68 |
| 3.5.4 | Swarm Intelligence | 71 |
| | References | 76 |
| 4 | Case of Study | 79 |
| 4.1 | Case Description | 79 |
| 4.2 | Finite Element Method Based Modeling. | 79 |
| 4.2.1 | Model Description. | 79 |
| 4.2.2 | Outcomes of the FEM. | 80 |
| 4.3 | Empirical Modeling | 85 |
| 4.3.1 | Statistical Modeling. | 85 |
| 4.3.2 | Neural Network-Based Modeling | 86 |
| 4.4 | Optimization | 89 |
| 4.5 | Concluding Remarks | 91 |
| | References | 91 |
| | Index | 93 |