



Lecture Notes in Mechanical Engineering

Caterina Rizzi ·

Angelo Oreste Andrisano ·

Francesco Leali · Francesco Gherardini ·

Fabio Pini · Alberto Vergnano *Editors*

Design Tools and Methods in Industrial Engineering

Proceedings of the International
Conference on Design Tools and
Methods in Industrial Engineering,
ADM 2019, September 9–10, 2019,
Modena, Italy



Springer

Lecture Notes in Mechanical Engineering

Lecture Notes in Mechanical Engineering (LNME) publishes the latest developments in Mechanical Engineering - quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering. Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

To submit a proposal or request further information, please contact the Springer Editor in your country:

China: Li Shen at li.shen@springer.com

India: Dr. Akash Chakraborty at akash.chakraborty@springernature.com

Rest of Asia, Australia, New Zealand: Swati Meherishi at swati.meherishi@springer.com

All other countries: Dr. Leontina Di Cecco at Leontina.dicecco@springer.com

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at <http://www.springer.com/series/11693> or contact Leontina.dicecco@springer.com

Indexed by SCOPUS. The books of the series are submitted for indexing to Web of Science.

More information about this series at <http://www.springer.com/series/11236>

Caterina Rizzi · Angelo Oreste Andrisano ·
Francesco Leali · Francesco Gherardini ·
Fabio Pini · Alberto Vergnano
Editors

Design Tools and Methods in Industrial Engineering

Proceedings of the International
Conference on Design Tools
and Methods in Industrial Engineering,
ADM 2019, September 9–10, 2019,
Modena, Italy

Editors

Caterina Rizzi
Dipartimento di Ingegneria Gestionale,
dell'Informazione e della Produzione
Università di Bergamo
Dalmine, Italy

Francesco Leali
Dipartimento Di Ingegneria "Enzo Ferrari"
Università Di Modena E Reggio Emilia
Modena, Italy

Fabio Pini
Dipartimento Di Ingegneria "Enzo Ferrari"
Università Di Modena E Reggio Emilia
Modena, Italy

Angelo Oreste Andrisano
Dipartimento Di Ingegneria "Enzo Ferrari"
Università Di Modena E Reggio Emilia
Modena, Italy

Francesco Gherardini
Dipartimento Di Ingegneria "Enzo Ferrari"
Università Di Modena E Reggio Emilia
Modena, Italy

Alberto Vergnano
Dipartimento Di Ingegneria "Enzo Ferrari"
Università Di Modena E Reggio Emilia
Modena, Italy

ISSN 2195-4356

ISSN 2195-4364 (electronic)

Lecture Notes in Mechanical Engineering

ISBN 978-3-030-31153-7

ISBN 978-3-030-31154-4 (eBook)

<https://doi.org/10.1007/978-3-030-31154-4>

© Springer Nature Switzerland AG 2020

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.

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.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The ADM 2019 International Conference, organized by the Italian Association of Design Methods and Tools for Industrial Engineering (ADM), brings the tradition of dissemination meetings back to life. The event in fact represents the reopening of the biennial international conferences organized by ADM in the years in which the JCM Conference (joint conference of ADM, INGEGRAF and S.mart) is not held.

The opportunity arose from the intention of all members of the Italian Association of Design Methods and Tools for Industrial Engineering to express gratitude to Prof. Angelo O. Andrisano, Rector of the University of Modena and Reggio Emilia.

As a member, adviser and President of the ADM board, Prof. Andrisano has with his skills, excellent professionalism, vision and passion offered a significant contribution to raising the works of the association to the highest levels.

As a very appreciated rector, Prof. Andrisano has moreover brought prestige to the association, stimulating the pride of all its members.

The ADM 2019 International Conference has been made possible with will and support of all the members of the ADM board, as well as the sensitivity of all the members of the Scientific Council, in particular the Coordinator, Prof. Caterina Rizzi. Moreover, a fundamental contribution was given by the Scientific Societies, INGEGRAF and S.mart, whom I sincerely thank.

I also thank all the members of the scientific and the organizing committees and Eng. Francesco Gherardini, who has effectively taken care of significant organizational aspects.

Special thanks go to all the authors and all the Italian and international reviewers for the high scientific level achieved by the papers, which has led to the publication of the research works in this prestigious book.

Finally, I thank all the ADM members. Their contribution has been fundamental for the organization of the ADM 2019 International Conference.

Vincenzo Nigrelli
ADM President

Letter to the Authors

Dear Attendees and Authors,

It is a great honour and a pleasure to welcome you to the ADM 2019 International Conference, held in Modena, Italy, 9–10 September 2019. The conference is hosted by the University of Modena and Reggio Emilia, a globally renowned university located in the heart of the Italian Motor Valley.

The conference aims at sharing knowledge, experience and up-to-date scientific information in the areas of design and manufacturing, with links between industry and academia. It provides a forum for researchers, educators and professional engineers for the dissemination and exchange of their latest research results.

Through the exchange of ideas, ADM 2019 intends to facilitate the creation of multidisciplinary cooperation and developments and discoveries for new product design and manufacture, health care, transportation and environment.

This book collects more than 80 scientific papers across a wide range of session topics that cover a broad spectrum of themes including theoretical issues, methods, tools, processes and case studies. The topics span from technical representation and geometric modelling to virtual/augmented reality, virtual ergonomics, human factors, human–machine interactions, knowledge management, additive manufacturing and many other subjects applied in different contexts, such as automotive, agriculture, cultural heritage and health care. They provide opportunities for interaction and for understanding how the application of emerging technologies impact on critical engineering issues activities such as product design, manufacturing, management and integration of information throughout the life cycle.

We have also the privilege to host three outstanding keynote speakers. The first is Prof. Angelo Oreste Andrisano (Rector of the University of Modena and Reggio Emilia, Italy) at the opening plenary session with a speech dealing with four decades of changes in the university and in our scientific sector. The others are two experts from industry: Dr. Massimo Giannozzi (Materials Engineering Manager, F1 Team Ferrari), with a speech on materials and processes for automotive design with a focus on additive manufacturing technologies, and Dr. Cécile Doan (Head of CATIA Strategy, Market Development and Finance—Dassault Systèmes,

Vice President) with a speech on simulation-driven design in industry: tools and future trends.

To conclude, I would like to thank all the authors for their valuable contribution to the book and each and every one of you for making ADM 2019 successful with your expertise, commitment and active engagement. Special thanks go to the Program Chair, Prof. Francesco Leali, and to the members of the Organizing Committee for their tremendous efforts for making this conference possible.

We sincerely hope that you will enjoy the conference, the Gala Dinner @ MEF—Museo Enzo Ferrari—and the beautiful Modena city.

Caterina Rizzi
Conference Chair

Introduction

This book collects the proceedings of the ADM 2019 International Conference, entitled “Design Tools and Methods in Industrial Engineering”, held in Modena, Italy, on 9–10 September 2019.

This is not the first time that an event organized by ADM (formerly known as Italian Association of Machines Design, today renamed the Italian Association of Design Methods for Industrial Engineering) or by our scientific sector (ING-IND/15) takes place in Modena. I am pleased to remember the “ADM day” held at the Military Academy of Modena in 2008, as well as the ING-IND/15 workshop organized in 2009 in the hills of Bologna, not far from Modena.

However, this conference is particularly significant, for the reasons I wish to summarize here.

Firstly, the ADM Conference constitutes a new international, permanent event held in Italy, aimed at disseminating cutting-edge research to a national and international audience. For several years, our association has had a collaborative relationship with the Spanish members of INGEGRAF and the French members of S.mart (formerly AIP-PRIMECA), with whom we organize the International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing (JCM) every two years. This event is hosted alternately by one of our three countries. Therefore, the ADM International Conference was born from the need for an event “in the middle”, to strengthen the international research network and to meet our colleagues in Italy. As a matter of fact, the ADM 2019 scientific committee was joined by Spanish and French colleagues, as well as German, Swedish, Norwegian and American ones, thanks to partnerships created by our “Enzo Ferrari” Department of Engineering (Modena) over the years.

Secondly, I am honoured to play the role of conference chair, a position that has led me to be one of the editors of this book. In more than 45 years of experience in this sector, I have seen many developments and evolutions. From the first use of CAD in the industrial sector, today we have reached a high multidisciplinary level and integration with information technology and electronics. The integration of novel tools and approaches in the industrial world is also due to the activity of our

scientific sector, capable of developing and integrating innovative tools and methodologies with the traditional themes of industrial engineering.

Finally, this conference is held in 2019, an important year for me, marking the conclusion of my mandate as Rector of the University of Modena and Reggio Emilia, as well as that of Full Professor for our scientific sector. As the Dean of the ADM association and the scientific sector, I enthusiastically accepted the proposal of Francesco Leali, my collaborator for years and now my colleague, to nominate the University of Modena and Reggio Emilia, and in particular our “Enzo Ferrari” Department of Engineering, as the location for the ADM 2019 International Conference. I would like to thank both him and my departmental colleagues, in particular the researchers of my lab, LaPIS lab, for organizing this event at the “Enzo Ferrari” Department of Engineering, so dear to me, having been one of its first promoters and founders.

Equally, I would like to thank the ADM President Prof. Vincenzo Nigrelli, and Prof. Caterina Rizzi, Coordinator of the ADM Scientific Council, whose members, in turn, I gratefully thank. Further thanks go to the publisher, Springer, who honoured us by publishing the proceedings of this first ADM International Conference in the series “Lecture Notes in Mechanical Engineering”.

Therefore, as editor of this first book, I hope that it will be the first of a new series of international conference proceedings underlining the leading role of our scientific sector in the international scene. The colleagues who will be hosting the next ADM conferences will have the burden, but above all the honour, of continuing this project that today we have started in Modena.

Angelo Oreste Andrisano
Honorary Conference Chair

Organization

ADM 2019 is organized by ADM—Italian Association of Design Methods and Tools for Industrial Engineering—in cooperation with the “Enzo Ferrari” Department of Engineering of the University of Modena and Reggio Emilia, Italy.

Organizing Committee

Francesco Leali	Università di Modena e Reggio Emilia, Italy
Francesco Gherardini	Università di Modena e Reggio Emilia, Italy
Fabio Pini	Università di Modena e Reggio Emilia, Italy
Alberto Vergnano	Università di Modena e Reggio Emilia, Italy

Scientific Committee

Conference Chair

Caterina Rizzi (ADM Scientific Committee Coordinator)	Università di Bergamo, Italy
---	------------------------------

Honorary Chair

Angelo O. Andrisano	Rector of Università di Modena e Reggio Emilia, Italy
---------------------	--

Conference Program Chair

Francesco Leali	Università di Modena e Reggio Emilia, Italy
-----------------	---

Members

Monica Bordegoni	Politecnico di Milano, Italy (ADM)
Rainer Börret	Aalen University, Germany
Pierre Castagna	Université de Nantes, France (S.mart)
Francisco Cavas-Martínez (INGEGRAF Scientific Council Director)	Universidad Politécnica de Cartagena, Spain
Aitor Cazón	TECNUM, Spain (INGEGRAF)
Vincent Cheutet	INSA Lyon, France (S.mart)
Paolo Di Stefano	Università dell'Aquila, Italy (ADM)
Benoit Eynard	Université de Technologie de Compiègne, France (S.mart)
Salvatore Gerbino	Università della Campania "Luigi Vanvitelli", Italy (ADM)
Francesco Gherardini	Università di Modena e Reggio Emilia, Italy (ADM)
Tim Grunwald	Fraunhofer Institute for Production Technology IPT, Germany
Sebastian Hähnel	Fraunhofer Institute for Production Technology IPT, Germany
Rafael Hidalgo Fernández	Universidad de Córdoba, Spain (INGEGRAF)
Carlos León Robles	Universidad de Granada, Spain (INGEGRAF)
Ruben Lostado Lorza	Universidad de la Rioja, Spain (INGEGRAF)
Cristina Manchado del Val	Universidad de Cantabria, Spain (INGEGRAF)
Ferruccio Mandorli	Università Politecnica delle Marche, Italy (ADM)
Cristina Martín Doñate	Univesidad de Jaén, Spain (INGEGRAF)
Rikardo Minguez Gabiña	Universidad del País Vasco, Spain (INGEGRAF)
Ramón Mirálbes Buil	Universidad de Zaragoza, Spain (INGEGRAF)
Maurizio Muzzupappa	Università della Calabria, Italy (ADM)
Vincenzo Nigrelli (ADM President)	Università di Palermo, Italy
Marcello Pellicciari	Università di Modena e Reggio Emilia, Italy (ADM)
Margherita Peruzzini	Università di Modena e Reggio Emilia, Italy (ADM)
Fabio Pini	Università di Modena e Reggio Emilia, Italy (ADM)
David Ranz	Universidad de Zaragoza, Spain (INGEGRAF)
José Ignacio Rojas Sola	Universidad de Jaén, Spain (INGEGRAF)
Terje Rølvåg	Norwegian University of Science and Technology, Norway
Bengt-Göran Rosén	Halmstad University, Sweden
Lionel Roucoules (S.mart Scientific Council Director)	ENSAM Aix-en-Provence, France

Max Schneckenburger
 Eneko Solaberrieta
 Miguel Suffo Pino
 Alberto Vergnano

 Enrico Vezzetti
 Matteo Zallio
 Marc Zolghadri
 (S.mart Deputy Director)

Aalen University, Germany
 Universidad del País Vasco, Spain (INGEGRAF)
 Universidad de Cádiz, Spain (INGEGRAF)
 Università di Modena e Reggio Emilia,
 Italy (ADM)
 Politecnico di Torino, Italy (ADM)
 Stanford University, USA
 SupMéca, France

Reviewers

Ambu, Rita
 Bartalucci, Chiara
 Bianconi, Francesco
 Bici, Michele
 Borgianni, Yuri
 Buonamici, Francesco
 Calì, Michele
 Campana, Francesca
 Cappetti, Nicola
 Carfagni, Monica
 Caruso, Giandomenico
 Cascini, Gaetano
 Ceruti, Alessandro
 Cocconcelli, Marco
 Concheri, Gianmaria
 Cristofolini, Ilaria
 Cucinotta, Filippo
 De Crescenzo, Francesca
 De Giorgi, Marta
 De Napoli, Luigi
 Di Angelo, Luca
 Favi, Claudio
 Ferro, Paolo
 Fiorineschi, Lorenzo
 Furferi, Rocco
 Gadola, Marco
 Germani, Michele
 Governi, Lapo
 Grazioso, Stanislao
 Grigolato, Luca
 Guardiani, Emanuele
 Ingrassia, Tommaso
 Liverani, Alfredo
 Mandolini, Marco

Marconi, Marco
 Martorelli, Massimo
 Marzullo, Domenico
 Meneghello, Roberto
 Montorsi, Monia
 Morabito, Anna Eva
 Motyl, Barbara
 Mozzillo, Rocco
 Naddeo, Alessandro
 Neri, Paolo
 Olivetti, Elena Carlotta
 Paoli, Alessandro
 Papetti, Alessandra
 Parras-Burgos, Dolores
 Piazzolla, Pietro
 Raffaelli, Roberto
 Razionale, Armando Viviano
 Redaelli, Davide Felice
 Regazzoni, Daniele
 Rizzuti, Sergio
 Rosa, Francesco
 Rosso, Stefano
 Rossoni, Marco
 Rotini, Federico
 Savio, Gianpaolo
 Schneckenburger, Max
 Servi, Michaela
 Speranza, Domenico
 Strozzi, Matteo
 Tamburrino, Francesco
 Uberti, Stefano
 Uccheddu, Francesca
 Vitali, Andrea
 Zippo, Antonio

Contents

Geometric Modelling and Analysis	
Shape and Texture Analysis of Radiomic Data for Computer-Assisted Diagnosis and Prognostication: An Overview	3
Francesco Bianconi, Mario Luca Fravolini, Isabella Palumbo, and Barbara Palumbo	
Mandible Morphing Through Principal Components Analysis	15
Giulia Pascoletti, Michele Cali, Cristina Bignardi, Paolo Conti, and Elisabetta M. Zanetti	
Flying Shape Sails Analysis by Radial Basis Functions Mesh Morphing	24
Michele Cali, Domenico Speranza, Ubaldo Cella, and Marco Evangelos Biancolini	
Effect of Cell Shape on Nanoindentation Measurements	37
Antonio Boccaccio, Michele Fiorentino, Vito Modesto Manghisi, Giuseppe Monno, and Antonio E. Uva	
Industrial Design and Ergonomics	
Nature Inspired Redesign of the Visual Appearance of an Industrial Product	47
Dolores Parras-Burgos, Francisco J. F. Cañavate, Francisco Cavas-Martínez, and Daniel G. Fernández-Pacheco	
Perceived Comfort and Muscular Activity: A Virtual Assessment of Possible Correlations	59
Nicola Cappetti, Alessandro Naddeo, Vittorio Maria Soldovieri, Ivan Vitillo, and Iolanda Fiorillo	

Experimental Comfort Assessment of a T-Shirt for Roadrunner	71
Enrico Avagnale, Rosaria Califano, and Iolanda Fiorillo	
Virtual Reality and Interactive Design	
Dynamic Projection for the Design of an Adaptive Museum Guide	85
Alma Leopardi, Silvia Ceccacci, and Maura Mengoni	
Enhancing Spatial Navigation in Robot-Assisted Surgery: An Application	95
Marco Gribaudo, Sandro Moos, Pietro Piazzolla, Francesco Porpiglia, Enrico Vezzetti, and Maria Grazia Violante	
Informing the Use of Visual Assets in Industrial Augmented Reality . . .	106
Michele Gattullo, Giulia Wally Scurati, Alessandro Evangelista, Francesco Ferrise, Michele Fiorentino, and Antonio Emmanuele Uva	
Integrated Design Tools for Model-Based Development of Innovative Vehicle Chassis and Powertrain Systems	118
Emanuele Bonera, Marco Gadola, Daniel Chindamo, Stefano Morbioli, and Paolo Magri	
A Handheld Mobile Augmented Reality Tool for On-Site Piping Assembly Inspection	129
Fabio Bruno, Loris Barbieri, Emanuele Marino, Maurizio Muzzupappa, and Biagio Colacino	
Multisensory Augmented Reality Experiences for Cultural Heritage Exhibitions	140
Marina Carulli and Monica Bordegoni	
Reverse Engineering, Digital Acquisition and Inspection	
Optical Stereo-System for Full-Field High-Frequency 3D Vibration Measurements Based on Low-Frame-Rate Cameras	155
Sandro Barone, Paolo Neri, Alessandro Paoli, Armando V. Razionale, Leonardo Bertini, and Ciro Santus	
CAD Reconstruction: A Study on Reverse Modelling Strategies	165
Francesco Buonamici, Monica Carfagni, Rocco Furferi, Lapo Governi, and Yary Volpe	
3D Scanning Procedure for the Evaluation of Lymphedema of Upper Limbs Using Low-Cost Technology: A Preliminary Study . . .	177
Andrea Vitali, Daniele Regazzoni, Caterina Rizzi, and Guido Molinero	
Low Cost Device to Perform 3D Acquisitions Based on ChAruCo Markers	189
Luca Puggelli, Rocco Furferi, and Lapo Governi	

Automatic Segmentation of Constant Radius Secondary Features from Real Objects	201
Luca Di Angelo, Paolo Di Stefano, and Anna Eva Morabito	
Comparison of Algorithms for Recognition of Cylindrical Features in a Voxel-Based Approach for Tolerance Inspection	213
Michele Bici and Francesca Campana	
Geometrical Product Specification and Tolerancing	
Tolerance Prediction for Determinate Assembly Approach in Aeronautical Field	229
Rocco Mozzillo, Ferdinando Vitolo, Paola Iaccarino, and Pasquale Franciosa	
Robust Parameter Analysis of Compliant Part Models for Computer Aided Tolerancing	241
Alberto Vergnano, Francesco Gherardini, Andrea Petruccioli, Enrico Bonazzi, and Francesco Leali	
Design for Manufacturing and Assembly	
An Improved Design Method for Net-Shape Manufacturing in Powder Metallurgy	257
Marco Zago, Mats Larsson, and Ilaria Cristofolini	
Design for Assembly in the Conceptual Development of Aircraft Systems	268
Claudio Favi, Giovanni Formentini, Francois Bouissiere, Claude Cuiller, Pierre-Eric Dereux, and Corentin Malchair	
A Knowledge Formalization Approach for Manufacturing Cost Estimation	279
Marco Mandolini, Claudio Favi, Federico Campi, and Roberto Raffaeli	
Vibration-Assisted Face Grinding of Mould Steel	291
Sebastian Hähnel, Tim Grunwald, Thomas Bergs, Fabio Pini, and Francesco Leali	
Virtual Design for Assembly Improving the Product Design of a Two-Way Relief Valve	304
Daniela Francia, Davide Seminerio, Gianni Caligiana, Leonardo Frizziero, Alfredo Liverani, and Giampiero Donnici	
Integrated Product and Process Design	
Improving the Shoes Customization Process Through a Digitally-Enabled Framework	317
Marco Marconi, Alessandra Papetti, Marta Rossi, and Giulia Di Domizio	

**Conceptual Design of a Functional Orthodontic Appliance
for the Correction of Skeletal Class II Malocclusion** 329
Luca Grigolato, Stefano Filippi, Daniela Barattin, Daniele Cantarella,
Won Moon, Roberto Meneghello, Gianmaria Concheri,
and Gianpaolo Savio

ANOVA Applied to the Taguchi Method: A New Interpretation 342
Sergio Rizzuti and Luigi De Napoli

**Proposal of a Framework Based on Continuous Brainwriting
to Expand Mindfulness in Concept Generation** 352
Sergio Rizzuti and Luigi De Napoli

**Morphological and Mechanical Characterization of P-Scaffolds
with Different Porosity** 361
Marta De Giorgi, Nunzia Gallo, Marta Madaghiele,
and Anna Eva Morabito

**Automotive Design Engineering: Material and Processes
Selection Problems** 373
Cristina Renzi, Luca Di Angelo, and Francesco Leali

**Integrated Methods for System Design, Simulation,
Analysis and Optimization**

Development of an Exhaust System for Agricultural Tractors 387
Stefano Uberti and Alessandro Copeta

A Topology Optimization of a Motorsport Safety Device 400
Filippo Cucinotta, Marcello Raffaele, and Fabio Salmeri

**A Cooperative Monitoring System for Diver Global Localization
and Operation Support** 410
Fabio Bruno, Loris Barbieri, Antonio Lagudi, Marino Mangeruga,
Francesco Pupo, and Alessandro Casavola

**Design and Simulation of the Hull of a Small-Sized Autonomous
Surface Vehicle for Seabed Mapping** 422
Loris Barbieri, Filippo Cucinotta, Alessandro Gallo, Fabio Bruno,
Maurizio Muzzupappa, Nadia Penna, and Roberto Gaudio

**Machine Health State Recognition Through Images Classification
with Neural Network for Condition-Based Maintenance** 432
Marco Rossoni, Andrea Fumagalli, and Giorgio Colombo

**Mechanics-Based Virtual Prototyping of Robots with Deformable
Bodies and Flexible Joints** 444
Stanislao Grazioso, Giuseppe Di Gironimo, and Antonio Lanzotti

Virtual Prototyping Design Method to Optimize Mechanical Spring Devices for MV Switch Disconnecter	458
Michele Cali, Salvatore Massimo Oliveri, and Sebastiano Zuccarello	
Design and Process Optimization of a Sintered Joint for Power Electronics Automotive Applications	470
Michele Calabretta, Alessandro Sitta, Salvatore Massimo Oliveri, and Gaetano Sequenzia	
An Integrated Approach to Optimize Power Device Performances by Means of Stress Engineering	481
Michele Calabretta, Alessandro Sitta, Salvatore Massimo Oliveri, and Gaetano Sequenzia	
Iterative and Participative Axiomatic Design Process to Improve Conceptual Design of Large-Scale Engineering Systems	492
Domenico Marzullo, Giuseppe Di Gironimo, Danilo Nicola Dongiovanni, Antonio Lanzotti, Rocco Mozzillo, and Andrea Tarallo	
Industrial Noise Modelling and Control: The Case of Natural Gas Distribution Systems	506
Chiara Bartalucci, Francesco Borchì, and Monica Carfagni	
Design Optimization: Tools and Methods for ETO Products	516
Paolo Cicconi, Marco Mandolini, Miriam Nardelli, and Roberto Raffaeli	
Design and Optimization of the Thermo-Mechanical Behavior in Glass Reinforced Polyamide 6 for Automotive Application	528
Silvia Barbi, Luca Cattani, Tiziano Manfredini, and Monia Montorsi	
A Fiber Optic Strain Gage Sensor for Measuring Preload in Thick Composite Bolted Joints	540
Marannano Giuseppe and Restivo Gaetano	
How to Classify Compliant Mechanisms	552
Davide Russo and Antonio Caputi	
Condition Monitoring Techniques of Ball Bearings in Non-stationary Conditions	565
Matteo Strozzi, Riccardo Rubini, and Marco Cocconcelli	
A CAE-Based Model of Aluminium Alloys Welded T-Joints for TEP Analysis	577
Federico Ruini, Fabio Pini, and Francesco Leali	
Dynamic Modelling of Mechanical System for the Packaging Industry	589
Raffaele Di Canosa and Francesco Pellicano	

Experimental Methods in Product Development

How Do Design Changes and the Perception of Product Creativity Affect Value?	601
---	------------

Yuri Borgianni, Lorenzo Maccioni, Guido Orzes, and Demis Basso

Improving the Efficiency of Design Protocol Analysis: An Approach to Speed Up the Coding Stage	612
---	------------

Niccolò Becattini, Gaetano Cascini, Jamie O'Hare, and Jean-Francois Boujut

Proof of Concept as a Multidisciplinary Design-Based Approach	625
--	------------

Diego Paderno, Ileana Bodini, and Valerio Villa

Experimental Study on Nonlinear Random Excitation	637
--	------------

Francesco Pellicano, Antonio Zippo, Giovanni Iarriccio, and Marco Barbieri

Knowledge and Product Data Management

A Knowledge Repository to Support Ecodesign Implementation in Manufacturing Companies	651
--	------------

Marta Rossi, Marco Marconi, Roberto Menghi, and Alessandra Papetti

Engineering Methods in Human-Related Applications

Deep CNN for 3D Face Recognition	665
---	------------

Elena Carlotta Olivetti, Jacopo Ferretti, Giansalvo Cirrincione, Francesca Nonis, Stefano Tornincasa, and Federica Marcolin

Multiperspective Ergonomic Assessment Approach for Human Centered Workplace Design	675
---	------------

Alessandra Papetti, Martina Scafà, Agnese Brunzini, and Marco Mandolini

Towards a Non-invasive Pectus Excavatum Severity Assessment Tool Using a Linear Discriminant Analysis on 3D Optical Data	686
---	------------

Michaela Servi, Rocco Furferi, Yary Volpe, Marco Ghionzoli, and Antonio Messineo

A Preliminary 3D Depth Camera-Based System to Assist Home Physiotherapy Rehabilitation	696
---	------------

Francesca Uccheddu, Lapo Governi, and Monica Carfagni

Design of a Customized Neck Orthosis for FDM Manufacturing with a New Sustainable Bio-composite	707
--	------------

Rita Ambu, Alessandro Motta, and Michele Cali

A Multi-layer Approach for the Identification and Evaluation of Collaborative Robotic Workplaces Within Industrial Production Plants	719
Ferdinando Vitolo, Agnese Pasquariello, Stanislao Patalano, and Salvatore Gerbino	
Accurate Liver 3D Reconstruction from MRE Images Using Shift-Compensated Volumetric Interpolation	731
Chiara Santarelli, Francesca Uccheddu, and Elisa Mussi	
A Multi-disciplinary Assessments Tool for Human-Machine Interaction	741
Margherita Peruzzini, Fabio Grandi, Marcello Pellicciari, Giovanni Berselli, and Angelo Oreste Andrisano	
Understanding the Human Motor Control for User-Centered Design of Custom Wearable Systems: Case Studies in Sports, Industry, Rehabilitation	753
Teodorico Caporaso, Stanislao Grazioso, Dario Panariello, Giuseppe Di Gironimo, and Antonio Lanzotti	
3D Digital Surgical Planning: An Investigation of Low-Cost Software Tools for Concurrent Design	765
Francesco Buonamici, Lorenzo Guariento, and Yary Volpe	
CAD Modeling for Evaluating LVOT Obstruction in Transcatheter Mitral Valve Replacement	776
Salvatore Pasta, Stefano Cannata, Giovanni Gentile, Tommaso Ingrassia, Vincenzo Nigrelli, and Caterina Gandolfo	
A Reliable Procedure for the Construction of a Statistical Shape Model of the Cranial Vault	788
Antonio Marzola, Michaela Servi, and Yary Volpe	
A New Approach to Evaluate the Biomechanical Characteristics of Osseointegrated Dental Implants	801
Vito Ricotta, Tommaso Ingrassia, Vincenzo Nigrelli, and Marco Zicari	
Biomechanical Analysis of a New Elbow Prosthesis	812
Vito Ricotta, Laura Bragonzoni, Giuseppe Marannano, Lorenzo Nalbhone, and Andrea Valenti	
Additive Manufacturing	
Adoption of Additive Technologies by Florence Industries: Designing a Survey Session	827
Francesco Saverio Frillici, Lorenzo Fiorineschi, Rocco Furferi, and Federico Rotini	

**Properties Enhancement of Carbon PA 3D-Printed Parts
by Post-processing Coating-Based Treatments 837**
Sandro Barone, Paolo Neri, Sara Orsi, Alessandro Paoli,
Armando V. Razionale, and Francesco Tamburrino

Sensor Embedding in a 3D Printed Flexure Hinge 848
Francesco Rosa, Diego Scaccabarozzi, Simone Cinquemani,
and Francesco Bizzozero

**A Virtual Design Process to Produce Scoliosis Braces
by Additive Manufacturing 860**
Davide Felice Redaelli, Fabio Alexander Storm, Emilia Biffi,
Gianluigi Reni, and Giorgio Colombo

**High Density AlSi10Mg Aluminium Alloy Specimens Obtained
by Selective Laser Melting 871**
Federico Uriati, Filippo Da Rin Betta, Paolo Ferro, Stefano Rosso,
Gianpaolo Savio, Gianmaria Concheri, and Roberto Meneghello

**Scale and Shape Effects on the Fatigue Behaviour of Additively
Manufactured SS316L Structures: A Preliminary Study 879**
Stefano Rosso, Roberto Meneghello, Gianmaria Concheri,
and Gianpaolo Savio

**Additive Manufacturing Challenges and Future Developments
in the Next Ten Years 891**
Antonio Bacciaglia, Alessandro Ceruti, and Alfredo Liverani

**Investigating the Relationships Between Additive Manufacturing
and TRIZ: Trends and Perspectives 903**
Barbara Motyl and Stefano Filippi

Optimizing the Nozzle Path in the 3D Printing Process 912
Manuel Iori and Stefano Novellani

A Build-Time Estimator for Additive Manufactured Objects 925
Luca Di Angelo, Paolo Di Stefano, and Emanuele Guardiani

3D Printed Materials for High Temperature Applications 936
Antonio Marzola, Elisa Mussi, and Francesca Uccheddu

**Optimization Design Strategy for Additive Manufacturing
Process to Develop 3D Magnetic Nanocomposite Scaffolds 948**
Antonio Gloria, Marco Domingos, Saverio Maietta, Massimo Martorelli,
and Antonio Lanzotti

Determination of Adhesive to Be Applied in the Fabrication of Prototypes Using FDM Techniques of 3D Printing in Component Parts Using ULTEM™ 1010 959
Miguel Suffo

Assessment of Design for Additive Manufacturing Based on CAD Platforms 970
Enrico Dalpadulo, Fabio Pini, and Francesco Leali

Author Index 983

Geometric Modelling and Analysis



Shape and Texture Analysis of Radiomic Data for Computer-Assisted Diagnosis and Prognostication: An Overview

Francesco Bianconi¹(✉), Mario Luca Fravolini¹, Isabella Palumbo²,
and Barbara Palumbo³

¹ Department of Engineering, Università degli Studi di Perugia, Via Goffredo
Duranti 93, 06135 Perugia, Italy

bianco@ieee.org, mario.fravolini@unipg.it

² Section of Radiation Oncology, Department of Surgical and Biomedical Sciences,
Università degli Studi di Perugia, Piazza Lucio Severi 1, 06132 Perugia, Italy
isabella.palumbo@unipg.it

³ Section of Nuclear Medicine and Health Physics, Department of Surgical
and Biomedical Sciences, Università degli Studi di Perugia, Piazza Lucio Severi 1,
06132 Perugia, Italy
barbara.palumbo@unipg.it

Abstract. There is increasing evidence that shape and texture descriptors from imaging data could be used as image biomarkers for computer-assisted diagnosis and prognostication in a number of clinical conditions. It is believed that such quantitative features may help uncover patterns that would otherwise go unnoticed to the human eye, this way offering significant advantages against traditional visual interpretation. The objective of this paper is to provide an overview of the steps involved in the process – from image acquisition to feature extraction and classification. A significant part of the work deals with the description of the most common texture and shape features used in the literature; overall issues, perspectives and directions for future research are also discussed.

Keywords: Shape · Texture · Radiomics ·
Computer-assisted medicine

1 Introduction

Recent technological advances including new imaging modalities as well as storing, sharing and computing resources have facilitated the collection of very large amounts of three-dimensional medical data [1]. In this scenario shape and texture analysis of such data has been receiving increasing attention during the last few years. The overall objective is that of extracting quantitative parameters from the imaging data (*biomarkers*) capable of correlating with clinical features such as disease phenotype and/or survival. The whole process, usually referred to as *radiomics*, can be regarded as an improvement on the traditional

practice wherein medical images were mostly used as pictures for qualitative visual interpretation only [2,3]. In the management of oncologic disorders, for instance, a number of studies have supported the use of radiomics for a variety of tasks including prediction of outcome [4,5] and response to treatment [6,7]; discrimination between benign, malignant, primary and metastatic lesions [8–10]; and classification of histologic subtypes [11].

Radiomics, however, is still a new discipline and definitely far from being mature. There are significant obstacles that prevent the application on a large scale – chief among them the lack of large enough datasets for building models and classifiers, and the absence of standards establishing how the biomarkers should be computed [12]. The objective of this paper is to provide an overview of the steps involved, discuss the open issues and indicate directions for future research. A significant part of the paper deals with the description of the most common texture and shape features used in the literature.

2 Methods

The flow-chart of Fig. 1 summarises the overall workflow in radiomics. Image acquisition is always the first step and can optionally be followed by a post-processing phase. Segmentation is then required to separate the region of interest (ROI) from the background. Feature extraction is the core of the procedure and consists of extracting a set of meaningful parameters (*features*) from the ROI. The features can undergo some post-processing step as for instance selection and/or reduction. Finally, the resulting data are fed to some classifier or regression model suitable for the required task.

2.1 Image Acquisition

There are three main classes of medical imaging modalities providing three-dimensional data [13]: Computed Tomography (CT), Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI).

Computed Tomography is based on the unlike absorption of X-rays by different tissue types, therefore the signal is proportional to the tissue density in this case [14]. Positron Emission Tomography estimates the metabolic activity of the tissue by measuring the radioactive decay of some specific radio-tracers. Those used in PET contain isotopes (e.g. ^{11}C , ^{15}O and ^{18}F) which emit positrons through β^+ decay. The positrons collide and annihilate with the electrons in the tissue, this way emitting two γ rays 180° apart that are detected by the sensors [15]. Finally, in Magnetic Resonance Imaging the signal comes from protons (hydrogen nuclei) contained in water and lipids. The signal in this case is proportional relaxation time – i.e. the time to return to the equilibrium magnetization state once the external magnetisation field is switched off [16].

In all the imaging modalities the scanning usually proceeds axially (head to feet), this way producing, as a result, a variable number of axial cross-sections with fixed size (slices). A three-dimensional voxel model is eventually reconstructed by piling up all the slices.

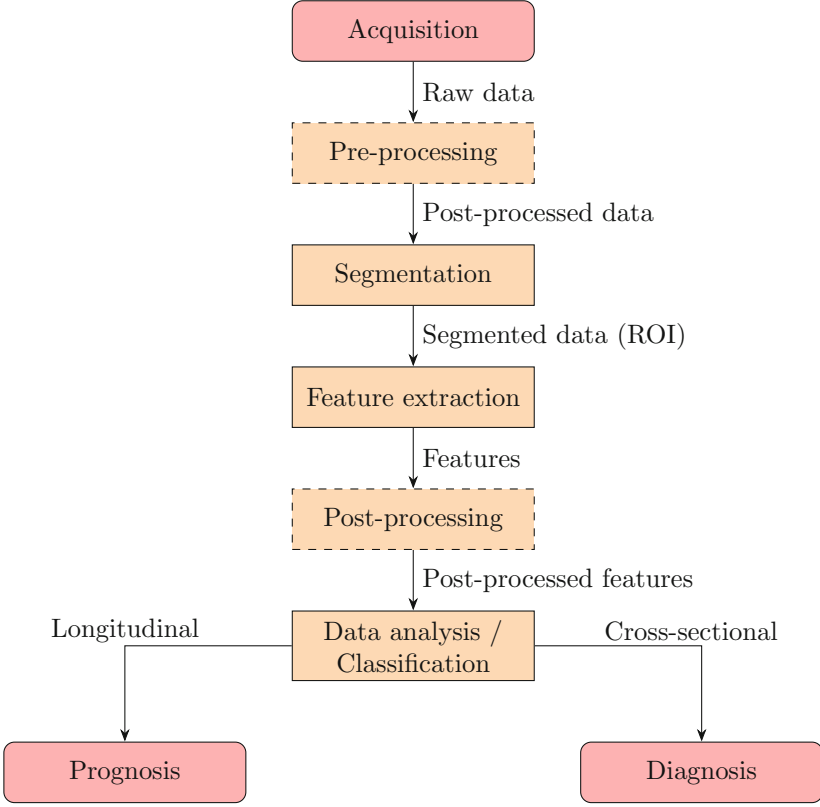


Fig. 1. The overall pipeline. Dashed lines indicate optional steps.

2.2 Pre-processing

Pre-processing usually involves one or more of the following operations: (1) *windowing* (rescaling), (2) *filtering* and (3) *resampling*. Although frequently overlooked, pre-processing is a fundamental step in the pipeline with significant effects on the overall results, as for instance shown in [17, 18].

Windowing consists of applying an upper and lower threshold to the raw intensity values returned by the scans, this way excluding from the analysis those values that fall outside the range. In CT, for instance, windowing is routinely used to exclude from the analysis those anatomic parts (e.g. bones) that are reputed not relevant to the disease investigated.

Filtering can be carried out either to reduce noise and/or highlight features at different spatial scales. A variety of methods can be used for this purpose, as for instance Butterworth smoothing [18], Gaussian [19] and Laplacian of Gaussian [7, 20] filters.

Resampling involves changing the number of bits (*bit depth*) used for encoding the intensity values. The bit depth of the raw data depends on the scanning

device and settings used (12 and 16 bit are standard values in the practice). These are usually reduced to lower values (*downsampling*) before feature extraction: eight, six and four bit and are common choices [6, 18, 21, 22].

2.3 Segmentation

The objective of segmentation is that of identifying the part of the scan (ROI) that is considered relevant to the analysis. A ROI usually represents a clinically relevant region, as for instance a potentially cancerous lesion (Fig. 2). Segmentation is a crucial step, for it provides the input to the subsequent phases. Unfortunately, this is also a tedious and time-consuming procedure. Although a number of methods have been investigated for automatising the process – these include, among the others thresholding [23, 24], region growing [23–25], edge detection [23, 24] and convolutional networks [26, 27] – segmentation remains by and large a manual procedure in which the experience and sensitivity of the physician play a major role. Besides, the decision whether to include or exclude dubious areas such as necrosis, atelectasis, inflammation and/or oedema is essentially the clinician’s responsibility and, as such, hard to automatise.

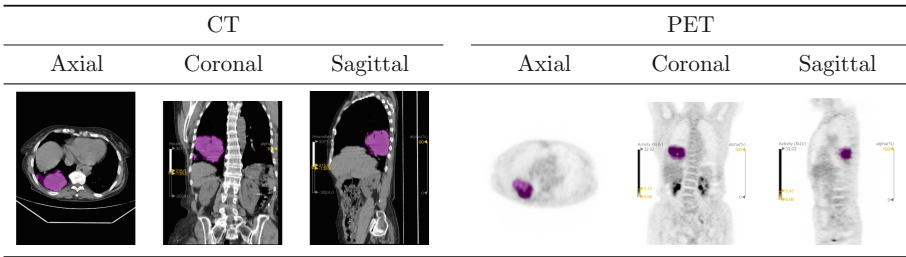


Fig. 2. CT (left) and PET (right) scans of a lung lesion with manually delineated ROI.

2.4 Feature Extraction

Feature extraction can be considered the ‘core’ of the whole procedure and consists of computing meaningful parameters from the regions of interest. There are two main strategies to feature extraction: the ‘hand-designed’ or ‘hand-crafted’ paradigm on the one hand, and Deep Learning on the other.

In the hand designed approach the functions for feature extraction (also indicated as *image descriptors*) are mostly designed by hand, the design process being based on some prior knowledge about filtering, perceptual models and/or relatively intuitive visual properties (e.g. coarseness, business, contrast, etc.) This model-driven, ‘a priori’ paradigm is independent on the data to analyse. By contrast, Deep Learning is a data-driven, ‘a posteriori’ strategy in which the descriptors are essentially shaped by the data. The feature extractors, in

this case, are based on sets of combinable blocks (layers) of which only the overall skeleton is defined a priori, and their behaviour depends on lots of free parameters whose values need to be determined by training over huge sets of data. In this paper we are mostly concerned with the hand-design paradigm; for an overview of Deep Learning and its potential applications in the field we refer the reader to Refs. [28–30].

Regardless the method used, there are some desirable properties that one would always expect from features. First, they should be *discriminative*, i.e.: they should enable good separation among the classes involved in the problem investigated (e.g. classification benign vs. malignant). Second, they should be *interpretable* on the basis of some physical characteristics (e.g. round/elongated, coarse/fine, etc.) Third, they should be *few*: this, again, facilitates interpretation, limits the computational overhead and reduces the chances of overfitting. Here below we briefly review some of the most common shape and texture features used in radiomics.

Shape Features. Shape features have been investigated as potential biomarkers for a range of diseases. In oncologic disorders, for instance, lesions presenting ill-defined (‘spiculated’) borders are considered suggestive of malignancy, aggressiveness and in general worse prognosis; whereas those with regular, well defined margins are more frequently indicative of benign or less aggressive lesions [31–33]. For a quantitative evaluation of shape different parameters have been proposed – among them *compactness*, *spherical disproportion*, *sphericity* and *surface-to-volume ratio* (Eqs. 1–4). In formulas, indicated with A the surface area of the ROI, V the volume and R the radius of a sphere with volume V we have:

$$\text{compactness} = \frac{V}{\sqrt{\pi}A^{2/3}} \quad (1)$$

$$\text{spherical dispr.} = \frac{A}{4\pi R^2} \quad (2)$$

$$\text{sphericity} = \frac{\pi^{1/3}(6V)^{2/3}}{A} \quad (3)$$

$$\text{surface-to-vol. ratio} = \frac{A}{V} \quad (4)$$

Compactness, spherical disproportion and surface-to-volume ratio from CT, for instance, were found predictive of malignancy in lung lesions [34]; surface-to-volume ratio from MRI showed potential to differentiate between clinically significant and non-significant prostate cancer [31]; and functional sphericity from PET images correlated with clinical outcome in non-small-cell lung cancer [32].

Texture Features

Basic Statistics. These are parameters that can be computed directly from the raw data with no further processing. Resampling is not required. They include: *mean*, *maximum*, *median*, *range*, *standard deviation*, *skewness* and *kurtosis* (for definitions and formulae see also [35]). All these features are by definition invariant to geometric transformations of the input data such as rotation, mirroring, scaling and/or voxel permutation. Most of these features are also rather intuitive and their implementation straightforward.

Histogram-Based Features. This kind of features are derived from the probability distribution (histogram) of the intensity levels within the ROI. Features like *energy* (Eq. 5 – sometimes also referred to as *uniformity*) and *entropy* (Eq. 6) are routinely used for assessing the ‘heterogeneity’ of tumour lesions. There is indeed evidence that higher heterogeneity may correlate with worse overall prognosis and response to treatment [36–39]. Histogram-based statistics are invariant to geometric transformations of the input data – just as basic statistics are – but they heavily depend on the resampling scheme used. In formulas, given N the number of quantisation levels and p the probability of occurrence of the i -th intensity level, we have:

$$\text{energy}_H = \sum_{i=0}^{N-1} [p(i)]^2 \quad (5)$$

$$\text{entropy}_H = \sum_{i=0}^{N-1} p(i) \log_2 [p(i)] \quad (6)$$

where entropy is expressed in bits in this case. Subscript ‘H’ is used to indicate that the features are computed from histograms and to differentiate them from those computed from co-occurrence matrices (see below).

Grey-Level Co-occurrence Matrices. Co-occurrence matrices (GLCM) represent the two-dimensional joint distribution of the intensity levels between pairs of voxels separated by a given displacement vector. By changing the orientation and the length of the vector GLCM can probe the local signal variation at different scales and orientations. Co-occurrence matrices, a classic tools in texture analysis, were originally designed for planar images [40] but their extension to three-dimensional data is straightforward [41]. In this case there are 26 possible orientations for a given scale and as many GLCM, of which, however, only 13 non-redundant. A GLCM with values mainly clustered around the main diagonal will indicate a texture with low variability; a highly dispersed matrix will be characteristic of a variable texture. To capture this behaviour one usually extracts some global parameters from the GLCM, as for instance *contrast*, *energy*, *entropy* and *homogeneity* (Eqs. 7–10). Again, these have shown potential as clinical biomarkers in a number of studies [5, 6, 22, 42]. Indicated with i and j the indices of the two voxels separated by a given displacement vector, we have:

$$\text{contr.}_{CM} = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (i-j)^2 p(i, j)}{(N-1)^2} \quad (7)$$

$$\text{energy}_{\text{CM}} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} [p(i, j)]^2 \quad (8)$$

$$\text{entr.}_{\text{CM}} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} p(i, j) \log_2 [p(i, j)] \quad (9)$$

$$\text{hom.}_{\text{CM}} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \frac{p(i, j)}{1 + |i - j|} \quad (10)$$

Other Texture Features. Texture analysis has been an area of intense research for more than forty years, and, as a results, the amount of available methods is huge. Among those that have received attention in the field of radiomics are: neighbourhood grey-tone difference matrices (NGTDM [6, 21, 22, 43]), grey-level run-length matrices (GLRLM [21, 22, 44]), Local Binary Patterns (LBP [17, 45]), Laws' masks [46, 47] and wavelets [48, 49]. For definitions and further details we refer the reader to the given references.

2.5 Post-processing

The features returned by the extraction phase can undergo further processing to (a) reduce their number and (b) increase their discrimination capability. The main strategies to achieve this goal are *feature selection* and *feature generation* [50]. The first aims at identifying the most discriminative features so as to reduce their overall number while retaining as much information as possible. This is particularly important in radiomics, where some shape and texture features tend to be highly correlated to each other, as recently shown in [51]. The second consists of generating new features from the original ones via some suitable transformation, as for instance Principal Component Analysis (PCA) and Independent Component Analysis (ICA) [50].

2.6 Data Analysis/Classification

The last step consists of feeding the features to a classifier to make predictions about the disease type (*computer-assisted diagnosis*) and/or the clinical outlook (*prognostication*). To this end suitable machine learning models and large enough sets of labelled data (*train set*) are required. As for the model, one can choose among a number of different solutions (e.g. linear classifiers, Support Vector Machines, Classification Trees, neural networks and/or a combination of them [50, 52]): the main problem is selecting the right model for the specific task. Getting the right data for training, however, can be rather hard, for it requires finding large enough sets of manually classified/annotated clinical records. For prognostication the data need also to be longitudinal, which implies following up on a cohort of patients for a long period of time.