Studies in Computational Intelligence

Data, Semantics and Cloud Computing

Volume 832

Editor-in-chief

Amandeep S. Sidhu, Biological Mapping Research Institute (BIOMAP), Perth, Australia

The purpose of this book series is to inform and educate its audience about big data, semantic web, cloud computing and the inter-connections between these fields. Books in this series will be mainly used at Basic and Intermediary Level for Computer Science Postgraduate Students, Researchers and Practitioners. It will cover a broad range of topics like:

1. Big Data and its Management
2. Data Mining
3. Data integration and Ontologies
4. Semantic Web Tools and Techniques
5. Web 2.0 and Web 3.0
6. Cloud Computing
7. *aaS: Infrastructure, Platform, Software, Storage as a Service
8. Novel architectural models for cloud computing
9. New parallel/concurrent programming models for cloud computing
10. Data Cloud
11. Data Security, Privacy, and Jurisdiction in the Cloud
12. Reliability of applications and services running on the cloud
13. Interoperability between different Utility Computing Platforms including Grids, and Clouds
14. Performance monitoring for cloud applications
15. Cloud use case studies

More information about this series at http://www.springer.com/series/11756

Joey Sing Yee Tan · Amandeep S. Sidhu

Real-time Knowledge-based Fuzzy Logic Model for Soft Tissue Deformation

Springer

Joey Sing Yee Tan
Complexity Institute
Nanyang Technological University
Singapore, Singapore

Amandeep S. Sidhu
Biological Mapping Research Institute
(BIOMAP)
Perth, Australia

ISSN 1860-949X ISSN 1860-9503 (electronic)
Studies in Computational Intelligence
ISSN 2524-6593 ISSN 2524-6607 (electronic)
Data, Semantics and Cloud Computing
ISBN 978-3-030-15584-1 ISBN 978-3-030-15585-8 (eBook)
https://doi.org/10.1007/978-3-030-15585-8

Library of Congress Control Number: 2019934357

© Springer Nature Switzerland AG 2019
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

Contents

1 Introduction 1
1.1 Overview 1
1.2 Research Background 4
1.3 Problem Statement 5
1.4 Objectives 7
1.5 Scope of Study 7
1.6 Outline of Dissertation 8
References 8

2 Background 11
2.1 Literature Reviews 11
2.1.1 Surgical Simulation 11
2.1.2 Physically-Based Deformable Models 14
2.1.3 Fuzzy Inference System 19
2.1.4 Graphical Hardware and Programming Optimisation 21
2.1.5 Summary 23
Bibliography 24

3 Methodology 31
3.1 Overview 31
3.2 Mass Spring Model (MSM) 31
3.2.1 Formulation 31
3.2.2 Determination of MSM Parameters 35
3.3 Knowledge-Based Fuzzy Mass Spring Model Parameters Controller (FMPC) 36
3.3.1 Reasoning Knowledge to Rules 37
3.3.2 Construction of Mamdani Fuzzy Inference System (M_FIS) 38

3.3.3 Construction of Sugeno Fuzzy Inference System (S_FIS) . . . 41
3.3.4 Construction of Sugeno Fuzzy Inference System (S_FIS) . . . 42
3.4 CUDA Implementation . . . 43
3.5 Benchmark . . . 44
3.6 Summary . . . 46
References . . . 47

4 Fuzzy Inference System . . . 49
4.1 Overview . . . 49
4.2 Illustration of Problem . . . 50
4.3 Designation of Fuzzy MSM Parameters Controller (FMPC) . . . 51
4.3.1 Determination of Membership Functions (MFs) . . . 51
4.3.2 FMPC Rule Base . . . 53
4.4 FMPC Result and Analysis . . . 53
4.4.1 Obtaining the Stiffness Coefficient from FMPC . . . 53
4.4.2 Comparison Between Mamdani FIS, Sugeno FIS and Interval Type-2 FIS . . . 53
4.4.3 Comparison Between the Benchmark Model with the Fuzzy Approaches . . . 55
4.4.4 Graphs Similarity . . . 55
4.5 Discussions . . . 57
4.5.1 Obtaining the Stiffness Coefficient from FMPC . . . 57
4.5.2 Graphs Similarity . . . 59
4.6 Get Blast Wrapper Function . . . 59
References . . . 60

5 CUDA Implementation . . . 63
5.1 Overview . . . 63
5.2 Simulation Results . . . 63
5.2.1 CUDA Findings and Discussion . . . 63
5.3 Summary . . . 67

6 Conclusion . . . 69
6.1 Conclusion . . . 69
6.2 Limitation . . . 70
6.3 Future Works . . . 70

Appendix A: FMPC Rules . . . 71

Appendix B: CUDA Kernel . . . 79

Unlisted References . . . 87

List of Figures

Fig. 1.1 Group of novice surgeons observing the demonstration by the certified surgeon. *Source* http://www.flickr.com/photos/medicalmuseum 2
Fig. 1.2 Surgical training in virtual environment. *Source* http://cg.alexandra.dk 3
Fig. 2.1 The different generations of medical simulators (Delingette 1999) 13
Fig. 2.2 The elementary components of a fuzzy control system. Abstracted from Feng (2006): a survey on analysis and design of model-based fuzzy control system 19
Fig. 2.3 The hardware architecture of CPU and GPU where GPU devotes more transistors to data processing. Abstracted from: CUDA C Programming Guide (2013). 22
Fig. 3.1 The workflow of interrelation between the central processing unit (CPU) and graphical processing unit (GPU) throughout the simulation 32
Fig. 3.2 The 3D human liver modelling based on MSM 32
Fig. 3.3 Pseudo code of structural spring 33
Fig. 3.4 Pseudo code of flexion spring 34
Fig. 3.5 Block diagram of MSM in Simulink 34
Fig. 3.6 Conceptual diagram of FMPC fuzzy inference system 36
Fig. 3.7 Architecture of Mamdani fuzzy inference system (M_FIS) for FMPC 39
Fig. 3.8 Corresponding triangular membership function for the first input-liver fibrosis stage 39
Fig. 3.9 The adjustable rule viewer 41
Fig. 3.10 Mamdani FIS (M_FIS) with Gaussian membership functions 42
Fig. 3.11 Sugeno FIS (S_FIS) with Gaussian membership functions 43
Fig. 3.12 Interval type-2 FIS (IT2_FIS) with Gaussian membership functions 44

Fig. 3.13 CUDA implementation 45
Fig. 4.1 The adjustable rule viewer of FMPC 54
Fig. 4.2 Surface view of three different fuzzy approaches 55
Fig. 4.3 Comparison of benchmark model with the respective fuzzy approaches in terms of phase plane plot 55
Fig. 4.4 Comparison of benchmark model with the respective fuzzy approaches in terms of displacement versus time 56
Fig. 4.5 Comparison of benchmark model with the respective fuzzy approaches in terms of velocity versus time 56
Fig. 4.6 Comparison of the displacement corresponding to each of the stiffness value 58
Fig. 4.7 Trend view of benchmark with selected rules 58
Fig. 5.1 Comparison of CPU and GPU simulation runtime 64
Fig. 5.2 Comparison of CPU and GPU on the iteration within 60 s 64
Fig. 5.3 Timestep convergency between CPU and GPU 65
Fig. 5.4 CUDA-based simulation of liver deformation 65

List of Tables

Table 2.1 The requirement of accuracy over efficiency in different simulation 14
Table 2.2 Previous works on applications based on FIS 21
Table 3.1 The range of ideal human liver parameters (Kerdok 2006) 35
Table 3.2 The "AND" intersection between the inputs. 38
Table 3.3 The benchmark parameters. 46
Table 4.1 Graphs similarity between benchmark model with fuzzy approaches 56
Table 4.2 Outputs of the corresponding stiffness coefficient based on selected rules. 57