Springer Series on Touch and Haptic Systems

Gianni Campion

The Synthesis of Three Dimensional Haptic Textures: Geometry, Control, and Psychophysics

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ISSN 2192-2977 e-ISSN 2192-2985
ISBN 978-0-85729-575-0 e-ISBN 978-0-85729-576-7
DOI 10.1007/978-0-85729-576-7
Springer London Dordrecht Heidelberg New York

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Control Number: 2011928918

Cover design: deblik

Printed on acid-free paper

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

To Elena

Series Editors' Foreword

Haptics is a multi-disciplinary field with researchers from Psychology, Physiology, Neurology, Engineering, and Computer Science (amongst others) that contribute to a better understanding of the sense of touch, and research on how to improve and reproduce haptic interaction artificially in order to simulate real scenarios.

The "*Springer Series on Touch and Haptic Systems*" is a new *Springer* book series published in collaboration with the EuroHaptics Society. It is focused on publishing new advances and developments in all aspects of haptics. The goal is to obtain a fast dissemination of the latest results in order to stimulate the interaction among members of the haptics community and to promote a better understanding of touch perception and find the most suitable technologies to reproduce and simulate haptic environments.

The first issue of this series has been prepared by Gianni Campion, and is based on his PhD thesis. The content is focused tactile texture perception, a highly relevant topic in the field of haptics, and covers the simulation of textures and their evaluation with psychophysical methods.

The selection of this thesis for publication reflects the interest in the topic of texture perception and the high quality of the work. Being a thesis, it covers the topic in a very focused manner and analyzes it in considerable depth. As series editors we will continue to encourage this kind of publication as well as supporting publication of books focused on more general topics.

Finally, the series editors would like to thank the EuroHaptics Society for promoting haptics and for supporting this exciting new book series by Springer on Touch and Haptic Systems. Moreover, we would also like to thank all the members of the Series Editorial Advisory Board for their contributions in reviewing and so ensuring high quality of the publications.

Manuel Ferre
Marc O. Ernst
Alan Wing

Foreword

"The Synthesis of Three-Dimensional Haptic Textures: Geometry, Control and Psychophysics" by Gianni Campion under the advisement of Dr. V. Hayward presents a series of innovative tools that can be used to remove the artifacts from haptic rendering of textures. The main contributions include a complete platform, device, and synthesis algorithm, as well as evaluation of the techniques.

Overall, this book presents an all-front attack and very in-depth investigation of all components involved in haptic rendering of textures: hardware, software and psychophysics. The proposed techniques are effective and clever. I have worked in these areas for over a decade. There is a huge collection of literature in all these areas. I'm impressed that the work has done an excellent effort in surveying prior research, analyzing previous work, proposing new points of view, and synthesizing techniques to improve the overall rendering performance of haptic textures. The technical writing of the book is clear, coherent, carefully thought-out and well-organized. The diagrams and captured images clearly illustrate the basic concepts and further enhance the overall presentation. I believe the findings and results would be of significant interest to the haptics and robotics community.

Chapel Hill
December 2010

Ming Lin

Foreword

Working with Gianni Campion has been a most gratifying experience. Gianni started out as a self proclaimed computer scientist who would not even touch a screwdriver with a six-foot pole, but ended up having fun in the workshop making (simple) parts with the lathe more often than he would care to confess. The results of his voracious intellectual curiosity are evident throughout his work which is a must-read for anyone interested in haptic virtual environments where the surfaces are, as they should be, not smooth.

Gianni, again, congratulations for a job well done.

Paris
December 29, 2010

Vincent Hayward

Acknowledgements

I would like to thank Prof. Vincent Hayward for his kind supervision, his willingness to share his (numerous) ideas and insights, and for his generous style of teaching.

My colleagues in the Haptics Laboratory were always open to discuss the most various topics, the majority of which were not even loosely related to this thesis. I would like thank them in random order: Andrew Gosline with his magnets, Qi Wang, Hsin-Yun Yao and the PCBS, Mohsen Mahvash, Vincent Levesque the coder, Jerome Pasquero, Hanifa Dostmohamed, Omar Ayoub, Mounia Ziat, and Diana Garroway. I would not dare to forget the support of the people at the Center for Intelligent Machines, specially Cynthia Davidson, who has been a seamless interface with the bureaucratic side of McGill, and Jan Binder, who answered the too many requests I had for the System Administrator.

This research was supported in part by the Institute for Robotics and Intelligent Systems, in part by NSERC the Natural Sciences and Engineering Research Council of Canada, and by Immersion Corp. I would also like to acknowledge the reception of a PRECARN Inc. Scholarship, a McConnell McGill Major Scholarship, and a CGS-D2 Scholarship from NSERC.

Finally I thank my family for their support to this endeavor and Elena, who helped me through this effort.

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Chapter 1
Introduction

Abstract This chapter introduces the main topics discussed in the book and defines the scope of the research presented. Specifically, this book discusses the rendering of haptics textures with force-feedback haptic devices and takles the topic both from the engineering and the psychophysics angle.

1.1 Introduction

Human touch is a versatile sense. It is used to explore the environment, as a control mechanism for movement and manipulation, and even as a non-verbal communication channel; as an example, visually impaired people may rely on touch for reading. The discipline which studies the sense of touch is called *haptics* (from the Greek *haptô, hapsasthai*); the term *haptic* is an adjective meaning "Of or relating to the sense of touch" [1].

Despite the flexibility of the sense of touch, the development and availability of haptic interfaces greatly lags behind that of visual interfaces (e.g., monitors and TV) and audio technology (loudspeakers and headphones). In fact, the basic nature of tactile sensation is still under investigation. While visual stimuli are known to be electromagnetic radiations of certain wavelengths and audio stimuli are pressure waves reaching the eardrum, the basic nature of the haptic stimuli is yet to be fully understood. This lack of fundamental knowledge about the sense of touch is compounded by the lack of haptic devices capable of delivering controlled stimuli as rich as the contact interactions between the skin and the surface of an object. The divide between the natural stimuli and artificial equivalent is particularly pronounced when generating virtual textures, because of their significant high frequency components.

There are two main modalities of haptic interaction with objects: direct touch exploration requires the contact of the skin (usually a finger) with the object, the second is indirect touch, where the skin contacts a proxy and the proxy scans the object. Delivering controllable textured stimuli for bare finger exploration is extremely complex and, at the time of writing, very few attempts have been made with mixed results. The most daunting problem is the spatial resolution of the textures which can be resolved by touch. Humans can perceive textural elements less than 200 μm apart, and delivering a controlled deformation to the skin at that scale is still not feasible. More encouraging results are obtained for indirect touch, where

G. Campion, *The Synthesis of Three Dimensional Haptic Textures: Geometry, Control, and Psychophysics*, Springer Series on Touch and Haptic Systems,
DOI 10.1007/978-0-85729-576-7_1, © Springer-Verlag London Limited 2011

the user interacts with a surface through a proxy; but also in this case, the human somatosensory system can detect and discriminate stimuli to a level which cannot be attained by currently available proxy-based haptic devices.

Moreover, a single haptic device cannot render all the possible force signals, the same way a visual display cannot produce every possible visual stimulus. For example, the spatial resolution of a computer screen limits the size of the smallest feature displayable and the frequency of the spatial variations of light. Similar limitations occur in haptic devices and a framework for assessing the effects of those limitations is needed.

To compound this problem, the algorithms presented in the literature are discussed only in relation to their psychophysical properties, but their energy profile is never characterized, nor a formal passivity-based analysis is performed. As a result, it is extremely difficult to interpret the psychophysical results reported and it is impossible to extend those findings to haptic devices different from the one used in the specific example.

1.2 Scope

This book focuses on the problem of generating force-feedback textures precisely and free of artifacts. Force-feedback is understood to refer to the most common approach adopted to create touch sensations in virtual reality settings. Users "touch" a virtual environment through an electromechanical device acting like an intermediary [2]. The feeling of touching a virtual object is generated by varying the force acting on the proxy in response to the user motion.

This book deals with both haptic devices and the rendering algorithms. Regarding the former, it presents a set of conditions highlighting the sources of artifacts due to the haptic devices. Texture algorithms, on the other hand, are explored with a novel analytic tool derived from passivity theory that removes the imperfections of the rendering due to energy imbalance. This framework is used to validate a rendering platform (device and algorithm) which can be used to explore the perception of haptic textures. In particular, a psychophysical experiment aimed at investigating the equivalence between texture algorithms with regard to the roughness perception elicited is presented.

1.3 Overview

The book is organized in 10 chapters: this introduction, a literature review, five manuscripts, two chapters, and a summary.

Chapter 2 covers the previous work in the domain of haptic textures. It contains an overview of the most relevant haptic devices, a comprehensive list of the texture algorithms developed for force-feedback haptic textures, a survey of the major results in control applied to haptics (particularly the passivity analysis and the