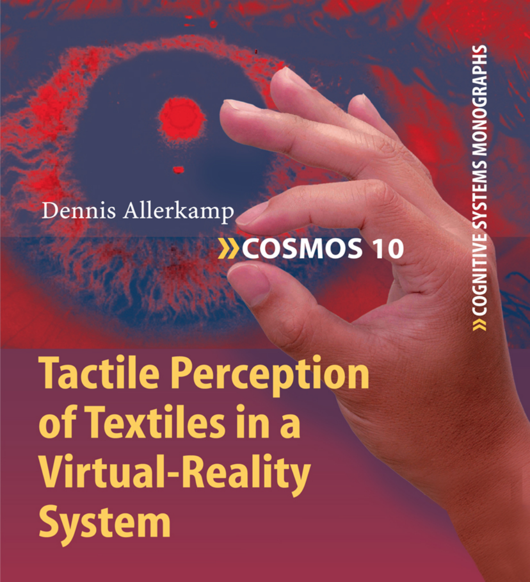

Dennis Allerkamp

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Tactile Perception of Textiles in a Virtual-Reality System

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Preface

This monograph originates from my work on the HAPTEX project. In December 2004 Prof. Franz-Erich Wolter, the head of the Institute of Man–Machine Communication of the Leibniz Universität Hannover, offered me the opportunity to participate in that EU funded project. Being a mathematician I had only very little experience in the field of haptic simulation in those days, but Prof. Wolter trusted in my ability to become acquainted with new fields of research in a very short time. I am still thankful for the confidence he has shown me.

Since then I indeed learned and found out a lot. With this monograph I try to pass on the knowledge I gained. Having a reader in mind who—like me at the beginning of the project—has no background in psychophysics, neurophysiology or textile engineering I will provide the necessary basics. The skilled reader may safely skip these parts. Nevertheless I presume some basic knowledge in mathematics. I hope that this thesis might help a newcomer to discover the fascinating field of tactile simulation.

This work would not have been possible without the funding of the project "HAPtic sensing of virtual TEXtiles" (HAPTEX) under the Sixth Framework Programme (FP6) of the European Union (Contract No. IST-6549). The funding is provided by the Future and Emerging Technologies (FET) Programme, which is part of the Information Society Technologies (IST) programme and focuses on novel and emerging scientific ideas. For inventing this project and accordingly requesting the funding I thank Prof. Nadia Magnenat-Thalmann, Dr. Harriet Meinander, Prof. Franz-Erich Wolter, Dr. Ian Summers and P.Eng. Fabio Salsedo.

Special thanks go to my thesis advisor Prof. Franz-Erich Wolter for his guidance and support throughout my work on my PhD thesis which has greatly benefited from all his feedback. I hope I inherited some of his good sense for interesting and profound research.

My research was influenced a lot by Dr. Ian Summers who originally worked on the subject of tactile simulation. He not only provided several

tactile displays for the experiments but also shared a lot of his knowledge and experience. I really appreciate I was able to work with him.

I also thank Prof. Nadia Magnenat-Thalmann for the coordination of the HAPTEX project. She always applied very high standards to our research work. This was sometimes very stressful but the project would not have been nearly as successful as without her leadership. I appreciate her willingness to be a member of my examination committee.

I really enjoyed the interdisciplinary collaboration within the HAPTEX project. I thank all the team members for the interesting discussions and the positive working atmosphere. I would like to give a special mention to Guido Böttcher; we worked closely together on the haptic rendering software and complemented each other very well. It was a pleasure to work with him.

I had the pleasure of working with some very talented students who contributed to my research: I thank (in alphabetical order) Steffen Blume, Daniel Glöckner, Tjard Köbberling, Karin Matzke and Natalya Obydenna. I also thank Steffen Blume, Wiebke Frey and Iris Lieske for proofreading the manuscript and for the helpful discussions. The experiments conducted for my research were only possible because numerous persons voluntarily participated as probands. I thank all of them for their support. Finally, I really appreciate the moral support of my colleagues, friends and especially of my family. Thank you!

Hannover, March 2010 Dennis Allerkamp

Contents

Acronyms

ACM	autocorrelation matrix
CRA	correlation–restoration algorithm
DAC	digital–analogue converter
DFT	discrete Fourier transform
DIP	dual in-line package
DOF	degrees of freedom
FFT	fast Fourier transform
fps	frames per second
IC	integrated circuit
IPC	inter-process communication
jnd	just noticeable difference
KES-F	Kawabata evaluation system for fabrics
lpi	lines per inch
MDS	multidimensional scaling
OPA	operational amplifier
PC	Pacinian mechanoreceptive afferent
RA	rapidly adapting mechanoreceptive afferent
rms	root mean square
SA1	slowly adapting type 1 mechanoreceptive afferent
SA2	slowly adapting type 2 mechanoreceptive afferent
SFM	statistical feature matrix
SFS	shape from shading
USB	Universal Serial Bus
VR	virtual reality

Chapter 1
Introduction

Virtual Reality (VR) has a lot of applications ranging from entertainment to mechanical design and medical training. VR systems are often used in training situations where training in a real environment would be inappropriate and possibly even dangerous. Pilots, for example, often practise on a flight simulator before flying with a new type of aeroplane. Interestingly, flight simulators are also sold as games for personal computers. Today, computer games are probably the most common VR systems.

VR systems can be categorised by the modalities they support. In today's systems the modalities of seeing and hearing are the most commonly employed as these are also the modalities in which we as human beings mostly exchange information. They require least effort in terms of energy transfer, the corresponding sensory receptors are concentrated in the retina and the cochlea and can be excited remotely with light and sound waves respectively.

In contrast to seeing and hearing the creation of appropriate haptic stimuli demands very sophisticated hardware. Firstly, the skin with its size of 1.5–2 m^2 is a very large organ. Therefore most haptic devices focus on a rather small part of the human body—usually the fingertip. Secondly, forces cannot be transmitted contact-free with current technology. Thus haptic devices always need direct contact to the parts of the skin where the forces are applied. Thirdly, the amount of energy is relatively high compared to other modalities, e.g. if one wants to simulate the lifting of an object with a mass of 500 g the haptic device has to create a force of approximately 5 N. All these properties make haptic simulation a complex task still presenting a lot of problems awaiting a good solution.

Today's VR systems provide haptic interaction with virtual objects only indirectly via tools like a thimble or a pen-like probe or more specialised tools like, for example, the yoke of a plane, the handle of a scalpel or the handles of a pair of scissors. These tools usually appear twice in a VR system: as end effector transmitting the forces from the haptic device and as a virtual representation of the tool in the simulated virtual environment. The VR system is responsible of matching the physical state of the end effector and its virtual representation. Therefore, these tools can be seen as link between the real and the virtual world. However, this rather simple solution has two drawbacks. Firstly, special end effectors have to be designed for

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different applications, e.g. an end effector imitating the handle of a scalpel is probably useless for flight training of aviators. Secondly, it is not possible to directly touch the virtual objects with the hand, which reduces the possible realism of a VR system.

In order to simulate direct touch the parts of the skin that are in contact with virtual objects have to be appropriately stimulated with a tactile display. Although there exists a large variety of tactile displays only very little research has been done on the tactile simulation of real objects. The latter is the topic of the work at hand. In order to further narrow the research question, the virtual objects to be simulated have been restricted to textiles and only one of the many different types of tactile displays was investigated.

This work was part of the EU funded HAPTEX project, which aimed at developing a VR system for the visual and haptic presentation of textiles (cf. [4, 1, 2]). The project was coordinated by the MIRALab at the University of Geneva which also contributed the physical based simulation system of the fabrics. The Biomedical Physics Group at the University of Exeter developed the tactile stimulator hardware and was responsible for the multimodal integration and validation. The PERCRO Laboratory at the Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna in Pisa developed the force-feedback hardware which also carried the tactile stimulator hardware. The SmartWearLab at the Tampere University of Technology provided a selection of fabrics together with measurements appropriate for the project. And the Welfenlab at the Leibniz Universität Hannover developed the haptic rendering software computing appropriate signals for the force feedback and the tactile devices.

The target scenario of the project is depicted in Fig. 1.1. The virtual cloth is attached to a fixed stand. The user can touch, squeeze, rub and stretch the fabric with the thumb and index finger, feeling appropriate tactile stimulation at the fingertips. Reaching the target scenario is a very challenging task, because force-feedback and tactile simulation have to be integrated, posing more than only mechanical

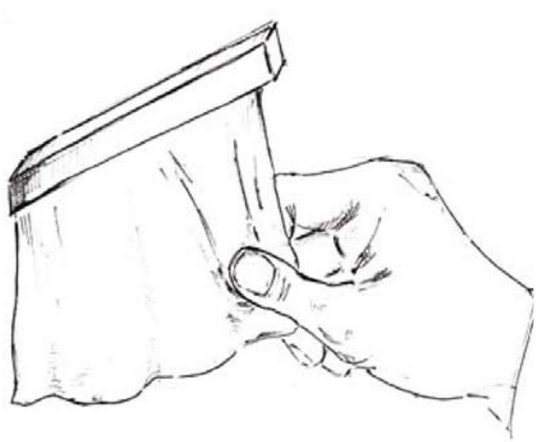

Fig. 1.1 HAPTEX final scenario from [1] (courtesy of PERCRO Laboratory)