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Mounia Ziat
Bentley University
mziat@bentley.edu

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Contents

Haptics for Human-Computer Interaction: From the Skin to the Brain

Mounia Ziat

Bentley University, USA; mziat@bentley.edu

ABSTRACT

In recent years haptics has received considerable attention from the field of Human-Computer Interactions (HCI) for its potential to provide more tangible and immersive interfaces. In this work, I present a selected review of research in haptics in an attempt to provide HCI and other fields a framework for understanding haptics that will help those fields design better interfaces and, ultimately, new and better experiences for those who interact with technology every day. This collection of essays exposes the reader to the haptics field, the haptic sense, and some examples of haptic technology. They cover over fifty years of research and terminology thus will be a handy reference for any researcher. In the conclusion, I examine the history in light of my own experiences and provide my take on haptics, HCI and what both communities can do to improve research and design.

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1

Introduction

Consider Figure 1.1 and then the environment around you as you are reading this. When you look closely at your surroundings and attend to your senses, a specific awareness of the world takes place. While writing these lines, I pause to look around and sense and feel all that I can. The sensations go beyond the shapes and colors of the laptop screen, the tables and chairs, and the cup in front of me. With a tool like a smartphone, I can record the colors and shapes, but there is something lacking. Each color, shape, and pattern that my eyes see also has a unique feeling of pressure, temperature, and texture. There is the weight of my clothes on my shoulder, the soft, forgiving cushion on the bench where I sit, the warm, smooth feel of the glass cup of green tea in my hands as I bring it to my lips, and the equally smooth but cool feel of the marble table. The plastic keys on my keyboard not only activate my cutaneous sense but also the proprioceptive and kinesthetic senses when the mechanical feedback of the keys offers their delicate resistance.

So much of what we call experience relies on our sense of touch and our sense of where our bodies are in the environment, i.e., proprioception, so much so that I long for a technology that could help me share those feelings. These non-visual sensations are not boring or secondary to

Figure 1.1: A morning at a coffee shop: notice the different textures in the environment.

me. Yes, I can see the pattern of the fabric on the bench, but even with my eyes closed I can easily follow the lines with my fingers and can tell you that it is a woven not a printed pattern. My leather purse has a similar temperature and pattern but is more pleasant to touch than the bench. Why more pleasurable? Is it because of my personal, idiosyncratic thoughts concerning ownership of it? Is it because the purse has utility to me as a container of other belongings? Is it possible that a texture can simply be more pleasurable to the touch without my knowledge of its history? (This will bring us to an aspect of touch that is often underrepresented in research; it is related to pleasantness and aversiveness to textures known as haptodysphoria - see Section 5).

Finally, by simply looking at the wooden floor and the wooden chair I feel I know something about them. If you have ever felt wood before, you can imagine each edge and groove on its surface. My feet, protected as they are by shoes, might not feel the tiny edges and grooves but they can certainly sense the separation between the boards and whether they are laid out evenly, which has considerable importance to me as an upright walking mammal. The device that communicates with our sense of touch and proprioception is called a haptic interface. From the mild resistance built into the volume knob on your car stereo that allows you to know how many degrees you are turning it without looking at it, to the full body suit that may soon come out of the science fiction novel to your home gaming system, haptics is a vital and growing part of the world around us and has the potential to augment many aspects of our lives.

Touch is not restricted to the hands and fingers; it is easily forgotten that every tiny portion of the human skin is sensitive to external stimuli; the reason we do not often think of this is likely related to the significant role of hands in human life (for a review on hands see Rosenbaum, 2017). Although some areas of the skin are more sensitive than others, every part of our body is a potential point of interface for a new technology or device. Some people may find certain areas of the body to be "off limits" while others may revel in total immersion.

Touch, like other senses, can trigger strong emotions; a caress of the arm can be perceived as intrusive or, on the contrary, exclusive and delightful depending on who is engaging in the act. Jourard had an interesting take on the emotional nature of touch where he constructed body maps for both females and males by identifying zones that can change the perceiver's view based on the social interaction with others (Jourard, 1966). Although the study is older and some new ones have updated these maps (Suvilehto *et al.*, 2015), it might be interesting to use haptic technology on the body rather than human touch and find out what the map is like when the human element is farther removed. In fact, several devices have been built that stimulate the tongue, the neck, the back, the belly, and other parts of the body (Bach-y-Rita, 1972; Kaczmarek *et al.*, 2000; Morrow *et al.*, 2016). Some have been more successful than others because of discomfort related to their location as well as social acceptance. Further discussion will be found in Section 5; I hope this haptic review will stimulate your imagination to create the technology of the future.

The main purpose of this collection of essays is to explore the potential role haptics can play in Human-Computer Interaction (HCI) and provide thoughts about avenues for future research. It should serve as a handy introduction to the ideas and trends in haptics. While each section will have background information aimed mostly at HCI researchers, each aims to be accessible to the educated layman as well. The purpose of these essays is not just to illustrate what is known but to inspire the reader to their thoughts with the hope that they may use the information presented to design better haptics for HCI.

This issue is organized by the principal subfields of touch and haptics. I divided the material into sections that include discussions on the psychology and physiology of touch as a baseline for HCI Research (Sections 3, 4, and 5), haptic technology (Section 6), haptic interaction with other perceptual modalities (Section 7), haptics as being used in user interfaces (Section 8), and mobile technologies (Section 9). Finally, the conclusion is my attempt to bring the two fields of haptics and HCI together and point out, from my perspective, what might be achieved with their creative use.

What more can be done with this information? I have only my perspective as a haptic researcher — one who ventures in HCI to design, hopefully, efficient technologies. As the fields of study where haptics is applied are diverse, I hope my multidisciplinary background provides an interesting perspective that allows me to explore all aspects of touch, ranging from engineering and computer science to psychology, psychophysics, and neuroscience.

For me, my research in haptics continues to fascinate. I hope the reader finds this collection of essays informative and educational, and that it will lead to the design of more efficient haptic interfaces for the HCI researcher and the world.

It has been a great pleasure to work and do research in the field of haptics, and it was humbling to be asked to contribute my thoughts.

Appendices

A

Haptics Conferences

Sources: Dov Adelstein and Ed Colgate's keynote talks at Haptics Symposium 2012, Vancouver, Canada; Asia Haptics, Eurohaptics, Haptics Symposium, and Worldhaptics conference websites. The three regional conferences: Asia Haptics, Eurohaptics, and Haptics Symposium meet on even years. On odd years, they joined to hold the Worldhaptics Conference. Another group of interest that gathers the most renowned names in haptic perception is the Tactile Research Group (TRG), a satellite group of the Psychonomic Society (PS) Meeting that has been around for more than 40 years. I organized the TRG meeting for three years in a row from 2009 to 2012.

- Early 1970s: Frank Gerald and Carl Sherrick (fathers of Saltation) started meeting other pioneers in tactile research; Jim Craig, Gary Rollman, Gene Leschelt, Paul Sheldon, Roger Cholewiak, John Kennedy, Pat Cabe, and anyone interested in haptic perception in their bedroom during the PS meetings.
- 1980 (St Louis, MO): The TRG meeting was held in a meeting room organized by Jim Craig. Since, TRG became an official satellite meeting of the annual meetings of PS.

- 1992 (Anaheim, CA): Ed Colgate and Dov Adelstein organized a haptic session at the ASME Winter Annual Meeting. The session was called “Symposium on Haptic Interfaces to Virtual Environments and Teleoperators”.
- 1993 (New Orleans, LA): The same conference was held, this time with the word haptic appearing in a session title and with 15 papers presented as opposed to only 8 the previous years. 1992-1993 was a huge transition in the development of haptic interfaces. 12 of these 15 papers use human participants.
- 1994 (Chicago, IL): Presentation of Thomas Massie’s paper on the Phantom Omni haptic device.
- 1995 (San Francisco, CA): Susan Lederman and Roberta Kaltzky, two pioneers in haptic perception, attended the conference.
- 1996 (Atlanta, GA): Lederman and Rob Howard co-chaired the conference that doubled in size.
- 1997 (Dallas, TX) and 1998 (Anaheim, CA): Same co-chairs.
- 1999 (Nashville, TE): Lynette Jones and Tim Salcudean were co-chairs.
- 2000
  - (Orlando, FL): Decision to leave ASME and join the IEEE VR conference.
  - (Zurich, Switzerland): The foundation of the Eurohaptics conference in Zurich in 2000 by Matthias Harders and Alan Wing.
- 2001 (Birmingham, UK): First EuroHaptics, with a small gathering, hosted by the University of Birmingham, UK, and organized by Alan Wing.

- 2002
  - EuroHaptics 2002 (Edinburgh, UK): Organized by the University of Edinburgh and Edinburgh College of Art with Mark Wright and Ann Marie Shillito as chairs.
  - Haptics Symposium 2002 (Orlando, FL): Because ASME is held in Winter and VR in the Spring, the next haptic conference was not held in 2001 but in 2002 with the first stand-alone proceedings.
- 2003
  - EuroHaptics 2003 (Dublin, Irland): Co-hosted by Trinity College Dublin and Media Lab Europe, and organized by Fiona Newell, Sile O'Modhrain, and Ian Oakley.
  - Haptics Symposium 2003 (Los Angeles, CA): Hong Tan and Blake Hannaford were co-chairs.
- 2004
  - EuroHaptics 2004 (Munchen, Germany): hosted by Technische Universitat Munchen, and organized by Martin Buss, Marc Ernst, and Matthias Harders.
  - Haptics Symposium 2004 (Chicago, IL): Antonio Bicchi and Hong Tan mentioned the fraction of haptic conferences and suggested a common conference.
- Worldhaptics 2005 (Pisa, Italy): First WorldHaptics co-chaired by Antonio Bicchi and Massimo Bergamasco. It also accentuated the importance of demos in the field.
- 2006
  - Eurohaptics 2006 (Paris, France): Chair Abderrahmane Kheddar.
  - Haptics Symposium 2006 (Arlington, VA): Co-chairs Blake Hannaford and Jen Wasenberger.

- Worldhaptics 2007 (Tsukuba, Japan): Chair Hiro Iwata.
- 2008
  - Eurohaptics 2008 (Madrid, Spain): Chair Manuel Ferre.
  - Haptics Symposium 2008 (Reno, NV): Co-chairs Blake Hannaford and Jen Wasenberger.
- Worldhaptics 2009 (Salt Lake City, UT): Chair John Hollerbach.
- 2010
  - Eurohaptics 2010 (Amsterdam, Netherlands): Chair Jan Van Erp.
  - Haptics Symposium 2010 (Waltham, MA): Co-chairs Allison Okamura and Karon MacLean.
- Worldhaptics 2011 (Istanbul, Turkey): Chair Cagatay Basdogan.
- 2012
  - Eurohaptics 2012 (Tampere, Finland): Chair Roope Raisamo.
  - Haptics Symposium 2012 (Vancouver, Canada): Co-chairs Karon MacLean and Marcia O'Malley.
- Worldhaptics 2013 (Daejon, Korea): Chair Dong-Soo Kwon.
- 2014
  - Asia haptics 2014 (Tsukuba, Japan): First Asia Haptics conference chaired by Hiroo Iwata. Asia Haptics is based on a unique concept and focused on interactive presentations with haptics demos.
  - Eurohaptics 2014 (Versailles, France): Chair Vincent Hayward.
  - Haptics Symposium 2014 (Houston, TX): Co-chairs Marcia O'Malley and Seungmoon Choi.
- Worldhaptics 2015 (Evanston, IL): Co-chairs Ed Colgate and Hong Tan.

- 2016
  - Asia Haptics 2016 (Kashiwanoha, Japan): Chair Hiroyuki Shinoda.
  - Eurohaptics 2016 (London, UK): Chair William Harwin.
  - Haptics Symposium 2016 (Philadelphia, PA): Co-chairs Seungmoon Choi and Katherine Kuchenbecker.
- Worldhaptics 2017 (Furstenfeldbruck, Germany): Sandra Hirche and Matthias Harders.
- 2018
  - Asia Haptics 2018 (Incheon, Korea): Chair Jee-Hwan Ryu with Hiroo Iwata and Dong-Soo Kwon as honorary chairs.
  - Eurohaptics 2018 (Pisa, Italy): Chair Antonio Frisoli.
  - Haptics Symposium 2018 (San Francisco, NV): Co-chairs Katherine Kuchenbecker and Greg Gerling.
- Worldhaptics 2019 (Tokyo, Japan): Co-chairs Hiroyuki Kajimoto and Hiroyuki Shinoda.
- 2020
  - Asia Haptics 2020 (Virtual): The conference was online. Originally it was held in Beijing, China. Chair Dangxiao Wang.
  - Eurohaptics 2020 (Leiden, Netherlands): The conference was hybrid due to the COVID pandemic. Chair Jan Van Erp.
  - Haptics Symposium 2020 (online): Co-chairs Greg Gerling and Yon Visell.
- Worldhaptics 2021 (Virtual): The conference was originally planned to be held in Montreal, Canada, but was moved to virtual due to the COVID pandemic. Co-chairs Vincent Levesque and Keyvan Hastrudi-Zaad.

- 2022
  - Asia Haptics 2022 (Beijing, China): Chair Dangxiao Wang.
  - Eurohaptics 2022 (Hamburg, Germany): Chair Thorsten A. Kern.
  - Haptics Symposium 2022 (online): Originally planned in Santa Barbara, CA but it was switched to online. Co-chairs Yon Visell and Veronica Santos.
- 2023
  - Worldhaptics 2023 (Delft, Netherlands): Co-chairs Michaël Wiertlewski and Astrid Kappers

B

Basic Physiology of Neurons and Fibers

B.1 Neurons

Neurons are information carriers in the human body. They can be sensory, interneurons, or motor neurons. They can have several shapes and sizes, and their axons can reach several meters long.

Figure B.1 depicts a typical neuron: the dendrites of a neuron (postsynaptic neuron) are the ones receiving the information from the terminal buttons of the presynaptic neuron. This information travels along the axon, the long tail, and produces what is known as an action potential. Note that neurons do not touch physically, and the transfer of the information from pre- to post-synaptic neurons occurs via a small gap called a synapse.

The axon of a neuron can be myelinated, which means it is encapsulated by myelin sheaths. Nerve impulses or action potentials travel faster in myelinated neurons than in unmyelinated ones.

B.2 Nerve Fibers

A nerve fiber or an axon can be either myelinated or unmyelinated. Several nerve fibers exist in the Peripheral Nervous System (PNS) and

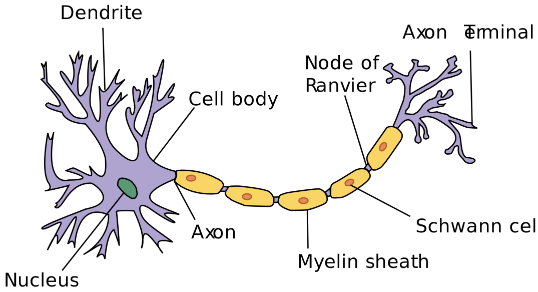

Figure B.1: Basic neuron structure.

the Central Nervous System (CNS), and the focus will only be on sensory and motor nerve fibers.

B.2.1 Sensory Nerve Fibers

Sensory nerve fibers are known as afferent neurons[1], and depending on their type, they innervate different haptic receptors. Mechanoreceptors are innervated by Aβ and Aδ fibers, proprioceptors by Aα and Aβ fibers, and nociceptors by C fibers.

They are classified by their transmission speed, with Aα being the faster. Except for C fibers, all are myelinated with Aδ having the thinnest sheaths. Table B.1 summarizes their characteristics (Basbaum *et al.*, 2009).

Table B.1: Nerve fibers classification.

Type	Diameter (μm)	Speed (m/s)	Myelinated
Aα (type I)	13-20	80-120	Yes
Aβ (type II)	6-12	33-75	Yes
Aδ (type III)	2-5	2-30	Thin
C (type IV)	0.2-1.5	0.5-2	No

[1]Carrying the information from PNS to CNS.

B.2.2 Motor Nerve Fibers

Also called efferent neurons[2], motor nerve fibers have similar classification names than their sensory counterpart; one reason they get often confused.

Aα, Aβ, Aδ, and C fibers are called Type I, II, III, and IV, respectively, from the thinker to the thinner.

[2]Carrying the information from CNS to PNS.

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