

Hasti Seifi · Astrid M. L. Kappers ·
Oliver Schneider · Knut Drewing ·
Claudio Pacchierotti · Alireza Abbasimoshaei ·
Gijs Huisman · Thorsten A. Kern (Eds.)

LNCS 13235

Haptics: Science, Technology, Applications

13th International Conference on Human Haptic Sensing
and Touch Enabled Computer Applications, EuroHaptics 2022
Hamburg, Germany, May 22–25, 2022, Proceedings

Founding Editors

Gerhard Goos

Karlsruhe Institute of Technology, Karlsruhe, Germany

Juris Hartmanis

Cornell University, Ithaca, NY, USA


Editorial Board Members

Elisa Bertino

Purdue University, West Lafayette, IN, USA

Wen Gao

Peking University, Beijing, China

Bernhard Steffen 

TU Dortmund University, Dortmund, Germany

Moti Yung 

Columbia University, New York, NY, USA

More information about this series at <https://link.springer.com/bookseries/558>


Hasti Seifi · Astrid M. L. Kappers ·
Oliver Schneider · Knut Drewing ·
Claudio Pacchierotti · Alireza Abbasimoshaei ·
Gijs Huisman · Thorsten A. Kern (Eds.)

Haptics: Science, Technology, Applications

13th International Conference on Human Haptic Sensing
and Touch Enabled Computer Applications, EuroHaptics 2022
Hamburg, Germany, May 22–25, 2022
Proceedings

Editors

Hasti Seifi 
University of Copenhagen
Copenhagen, Denmark


Oliver Schneider 
University of Waterloo
Waterloo, ON, Canada

Claudio Pacchierotti 
IRISA, Inria Rennes – Bretagne Atlantique
Rennes, France

Gijs Huisman 
Delft University of Technology
Delft, The Netherlands

Astrid M. L. Kappers 
Eindhoven University of Technology
Eindhoven, The Netherlands

Knut Drewing 
Justus-Liebig-University
Giessen, Germany

Alireza Abbasimoshai 
Hamburg University of Technology
Hamburg, Germany

Thorsten A. Kern 
Hamburg University of Technology
Hamburg, Germany



ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Computer Science
ISBN 978-3-031-06248-3 ISBN 978-3-031-06249-0 (eBook)
<https://doi.org/10.1007/978-3-031-06249-0>

© The Editor(s) (if applicable) and The Author(s) 2022. This book is an open access publication.

Open Access This book is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this book are included in the book's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the book's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

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

In this volume, you will find the proceedings of the EuroHaptics 2022 conference, held during May 22–24, 2022, in Hamburg, Germany. EuroHaptics is a major international conference, organized every two years, that features the latest advances in haptics science, technology, and applications. This year’s proceedings are open access. We follow the example given by the EuroHaptics 2020 team in Leiden and hope that future organizers will decide to do the same.

Organizing a conference of this size and international impact is always special and unique, but our conference in particular faced many challenges due to the circumstances. When Hamburg applied to host the event in 2020, we all assumed that the COVID-19 pandemic would be over by 2022. So, we originally planned optimistically for an on-site conference with global participation. However, the virus proved to be more persistent than expected, so we had to plan three versions of the conference in parallel: an on-site conference, a hybrid conference, and a virtual conference. Fortunately, the situation stabilized such that, with some reassurance from the scientific community, we were able to decide on an on-site conference. However, just as decisions were being made, geopolitical challenges arose from Russia’s war in Ukraine. Since this scientific community is traditionally more interested in interaction than in exclusion and separation, we again decided to keep open the opportunity for scientific cross-cultural exchanges. At the time of submitting this conference volume to production, more than 180 participants have confirmed their attendance, and a conference program has been designed with more than 140 papers ranging from oral presentations and posters to numerous hands-on demonstrations.

More than 350 (co-)authors submitted their contributions to the conference. In these uncertain times and after almost two years of the COVID-19 pandemic, the long paper category was comparatively small, with 65 papers, 36 of which were accepted for publication, yielding an acceptance rate of 55%. Impressively, 62 Work-In-Progress (WIP) short papers were submitted, of which 51 were accepted for inclusion in the conference, yielding an acceptance rate of 82%. In addition, we received 39 submissions for hands-on demonstrations and several industry exhibitors at the conference. We are excited to see how our scientific communication will evolve in the coming years, what will remain and what will revert to earlier times.

The entire evaluation and peer review process could not have been accomplished without the enthusiastic help of our haptics research community. In addition to the editorial board, 39 associate editors and 140 reviewers invested their time to provide valuable input to the organizers and authors. We are grateful for everyone’s help, especially with so many things happening around us.

Haptics research is a growing community. There is no conference or journal on robotics, actuators, psychology, neurology, or human-computer interaction without at least a few papers related to our research area. This proliferation can be seen as a threat to general haptics conferences. However, we see it as an opportunity, since there are no

conferences like EuroHaptics where technology, psychology, neuroscience, and applications coexist on an equal footing in a single-track event that promotes true interdisciplinary exchange. We are grateful to have been able to contribute to the progress of this community with a great team of editors and reviewers.

April 2022

Thorsten A. Kern
Hasti Seifi
Astrid M. L. Kappers
Oliver Schneider
Knut Drewing
Claudio Pacchierotti
Alireza Abbasimoshaei
Gijs Huisman

Organization

General Chair

Thorsten A. Kern Hamburg University of Technology, Germany

Program Chairs

Hasti Seifi University of Copenhagen, Denmark
Astrid M. L. Kappers Eindhoven University of Technology, The Netherlands

Conference Editorial Board

Oliver Schneider University of Waterloo, Canada
Knut Drewing Justus Liebig University Giessen, Germany
Claudio Pacchierotti CNRS, France
Alireza Abbasimoshaei Hamburg University of Technology, Germany

Publication Chair

Fady Youssef Hamburg University of Technology, Germany

Work-In-Progress Chair

Gijs Huisman Delft University of Technology, The Netherlands

Workshop Chair

Ilana Nisky Ben Gurion University of the Negev, Israel

Demo Chair

William Frier Ultraleap, UK

Awards Committee Chair

Jan van Erp University of Twente, The Netherlands

Local Chairs

Frank Steinicke University of Hamburg, Germany
Dennis Kähler Hamburg University of Technology, Germany

Student-Volunteer Chairs

Femke van Beek	Eindhoven University of Technology, The Netherlands
Sabrina Panëels	University of Kent, UK

Communication Chairs

Jana Ihrens	Hamburg University of Technology, Germany
Timon Hartwich	Hamburg University of Technology, Germany
Pravan Shelam	Hamburg University of Technology, Germany

Industry and Sponsorship Chairs

Julius Harms	Hamburg University of Technology, Germany
Elisa Santella	Grewus, Germany

Registration and Finance

Janick Lokocz	Hamburg University of Technology, Germany
Petra Schlegel	Hamburg University of Technology, Germany

Associate Editors

Yuki Ban	University of Tokyo, Japan
Çagatay Basdogan	Koc University, Turkey
Matteo Bianchi	University of Pisa, Italy
Mike Chen	National Taiwan University, Taiwan
Ildar Farkhatdinov	Queen Mary University of London, UK
Francesco Ferrise	Politecnico di Milano, Italy
William Frier	University of Sussex, UK
Greg Gerling	University of Virginia, USA
David Gueorguiev	Sorbonne University, France
Matthias Harders	University of Innsbruck, Austria
Keyvan Hastrudi-Zaad	University of British Columbia, Canada
Ali Israr	Purdue University, USA
Seokhee Jeon	Kyung Hee University, South Korea
Hiroyuki Kajimoto	University of Electro-Communications, Japan
Ayşe Kucukyilmaz	University of Nottingham, UK
Yoshihiro Kuroda	University of Tsukuba, Japan
Scinob Kuroki	NTT Communication Science Laboratories, Japan
Vincent Levesque	McGill University, Canada
Pedro Lopes	University of Chicago, USA
Monica Malvezzi	University of Siena, Italy
Anna Metzger	Justus-Liebig-Universität Gießen, Germany
Kouta Minamizawa	Keio University, Japan
Alessandro Moscatelli	University of Rome Tor Vergata, Italy

Shogo Okamoto	Nagoya Institute of Technology, Japan
Melisa Orta Martinez	Carnegie Mellon University, USA
Hannes P. Saal	University of Sheffield, UK
Sabrina Panëels	University of Kent, UK
Gunhyuk Park	Gwangju Institute of Science and Technology, South Korea
Evren Samur	Boğaziçi University, Turkey
Jeroen Smeets	Vrije University Amsterdam, The Netherlands
Massimiliano Solazzi	Institute of Communication Information and Perception Technologies, Italy
Eckehard Steinbach	Technical University of Munich, Germany
Yoshihiro Tanaka	Nagoya Institute of Technology, Japan
Jean-Louis Thonnard	University of Louvain, Belgium
Yasemin Vardar	Delft University of Technology, The Netherlands
Dangxiao Wang	Beihang University, China
Mounia Ziat	Northern Michigan University, USA
Femke van Beek	Eindhoven University of Technology, The Netherlands
Jan van Erp	University of Twente, The Netherlands

Reviewers

Yusuf Aydin	Massimiliano Di Luca
Arsen Abdulali	Catherine Dowell
Rochelle Ackerley	Mihai Dragusanu
Mehmet Ayyildiz	Knut Drewing
Hector Barreiro	Basil Duvernoy
Edoardo Battaglia	Jonathan Eden
Alexis Block	Mohamad Eid
Rebecca Boehme	Sonia Elizondo
Jonathan Browder	Sara Falcone
Rachael Burns	Simone Fani
Antonio Cataldo	Shane Forbrigger
Nathalia Cespedes	Euan Freeman
Francesco Chinello	Rebecca Friesen
Seungmoon Choi	Bruno Fruchard
Giorgos Christopoulos	Gregory Gerling
Simone Ciotti	Kaj Gijsbertse
Ed Colgate	Frederic Giraud
Giulia Corniani	Lili Golmohammadi
Luke Cox	David Gueorguiev
Heather Culbertson	Taku Hachisu
Nicole D'Aurizio	Reza Haghighi Osgouei
Thomas Daunizeau	Amy Kyungwon Han
Yuri De Pra	Jess Hartcher-O'Brien
Jonathan Delafield-Butt	Waseem Hassan
Benoit Delhayé	Alice Haynes

Hsin-Ni Ho
Mehdi Hojatmadani
Thomas Howard
Thomas Hulin
Nicolas Huloux
Inwook Hwang
Seokhee Jeon
Anis Kaci
Hiroyuki Kajimoto
Takaaki Kamigaki
HyeongYeop Kang
Mehrdad Kermani
Thorsten A. Kern
Humayun Khan
Konstantina Kiltene
Yeongmi Kim
Roberta Klatzky
Krishna Dheeraj Kommuri
Ayse Kucukyilmaz
Irene Kuling
Yuichi Kurita
Ki-Uk Kyung
Silvia Logozzo
Pablo Lopez-Custodio
Hojin Lee
Yanan Li
Tommaso Lisini Baldi
Pedro Lopes
Ottavia Maddaluno
Monica Malvezzi
Paul Marasco
Bogdan Maris
Stephen Mascaro
Anna Metzger
Mayumi Mohan
Rafael Morales
Tania Morimoto
Manivannan Muniyandi
Evelyn Muschter
Cara Nunez

Seungjae Oh
Stefano Papetti
Gunhyuk Park
Dario Pittera
Myrthe Plaisier
Mithun Poozhiyil
Narjes Pourjafarian
Pornthep Preechayasomboon
Ismo Rakkolainen
Teresa Ramundo
Ben Richardson
Colleen Ryan
Semin Ryu
Camille Sallaberry
Massimo Satler
Félicien Schiltz
Immo Schütz
Cecile Scotto
Yitian Shao
Craig Shultz
Benjamin Stephens Fripp
Minghui Sun
Hong Tan
Marc Teyssier
Alexander Toet
Matteo Toscani
Jan Van Erp
Jean Vroomen
Laurence Willemet
Judith Weda
Yannick Weiss
Alan Wing
Xiao Xu
Takumi Yokosaka
Yongjae Yoo
Kyle Yoshida
Shunsuke Yoshimoto
Hong Zeng
Tao Zeng
Loes van Dam

Contents

Haptic Science

Haptic Discrimination of Different Types of Soft Materials	3
<i>Müge Cavdan, Katja Doerschner, and Knut Drewing</i>	
Moving Hands Feel Stimuli Before Stationary Hands	12
<i>Knut Drewing and Jean Vroomen</i>	
Perception of Friction in Tactile Exploration of Micro-structured Rubber Samples	21
<i>Maja Fehlberg, Kwang-Seop Kim, Knut Drewing, René Hensel, and Roland Bennewitz</i>	
Influence of Prior Visual Information on Exploratory Movement Direction in Texture Perception.	30
<i>Michaela Jeschke, Aaron C. Zöller, and Knut Drewing</i>	
Guidance for the Design of Vibrotactile Patterns for Use on the Human Back	39
<i>Astrid M. L. Kapppers and Myrthe A. Plaisier</i>	
Speed Discrimination in the Apparent Haptic Motion Illusion.	48
<i>I. Lacôte, D. Gueorguiev, C. Pacchierotti, M. Babel, and M. Marchal</i>	
Neutral Point in Haptic Perception of Softness	57
<i>Anna Metzger, Anna Lotz, and Knut Drewing</i>	
Pilot Study on Presenting Pulling Sensation by Electro-Tactile Stimulation. . .	66
<i>Shota Nakayama, Mitsuki Manabe, Keigo Ushiyama, Masahiro Miyakami, Akifumi Takahashi, and Hiroyuki Kajimoto</i>	
A Preliminary Study on the Perceptual Independence Between Vibrotactile and Thermal Senses.	75
<i>Jaeyun Park, Jeongwoo Kim, Chaeyong Park, Seungjae Oh, Junseok Park, and Seungmoon Choi</i>	
Spatial Compatibility of Visual and Tactile Stimulation in Shared Haptic Perception	84
<i>Kimihiro Uemura, Hikari Yukawa, Kota Kitamichi, Mina Shibasaki, Kouta Minamizawa, and Yoshihiro Tanaka</i>	

Increasing Perceived Weight and Resistance by Applying Vibration to Tendons During Active Arm Movements	93
<i>Keigo Ushiyama, Akifumi Takahashi, and Hiroyuki Kajimoto</i>	
A Comparison of Haptic and Auditory Feedback as a Warning Signal for Slip in Tele-Operation Scenarios	101
<i>Femke E. van Beek, Quinten Bisschop, Kaj Gijsbertse, Pieter S. de Vries, and Irene A. Kuling</i>	
Experiencing Touch by Technology	110
<i>Judith Weda, Dasha Kolesnyk, Angelika Mader, and Jan van Erp</i>	
Effect of Focus Direction and Agency on Tactile Perceptibility	119
<i>Zane A. Zook and Marcia K. O'Malley</i>	
Haptic Technology	
Haptic Guidance for Teleoperation: Optimizing Performance and User Experience	129
<i>Leonie Becker, Bernhard Weber, and Nicolai Bechtel</i>	
A Multi-modal Haptic Armband for Finger-Level Sensory Feedback from a Prosthetic Hand	138
<i>Alexandre Berkovic, Colin Laganier, Digby Chappell, Thrishantha Nanayakkara, Petar Kormushev, Fernando Bello, and Nicolas Rojas</i>	
Sound Pressure Field Reconstruction for Ultrasound Phased Array by Linear Synthesis Scheme Optimization	147
<i>Jianyuan Chen, Shun Suzuki, Tao Morisaki, Yutaro Toide, Masahiro Fujiwara, Yasutoshi Makino, and Hiroyuki Shinoda</i>	
A Rotary Induction Actuator for Kinesthetic and Tactile Rendering	155
<i>Georges Daher, Stéphane Régnier, and Sinan Haliyo</i>	
Haptic Feedback for Wrist Angle Adjustment	164
<i>Michiel den Daas, Femke E. van Beek, and Irene A. Kuling</i>	
Larger Skin-Surface Contact Through a Fingertip Wearable Improves Roughness Perception	171
<i>David Gueorguiev, Bernard Javot, Adam Spiers, and Katherine J. Kuchenbecker</i>	
Expanding Dynamic Range of Electrical Stimulation Using Anesthetic Cream	180
<i>Takumi Hamazaki, Taiga Saito, Seitaro Kaneko, and Hiroyuki Kajimoto</i>	

Haptic Rattle: Multi-modal Rendering of Virtual Objects Inside a Hollow Container	189
<i>Emilie Hummel, Claudio Pacchierotti, Valérie Gouranton, Ronan Gaugne, Theophane Nicolas, and Anatole Lécuyer</i>	
Design of a 2-DoF Haptic Device for Motion Guidance	198
<i>Lisheng Kuang, Maud Marchal, Marco Aggravi, Paolo Robuffo Giordano, and Claudio Pacchierotti</i>	
Preliminary Design of a Flexible Haptic Surface	207
<i>Romain Le Magueresse, Frédéric Giraud, Fabrice Casset, Anis Kaci, Brigitte Desloges, and Mikael Colin</i>	
Human Self-touch vs Other-Touch Resolved by Machine Learning	216
<i>Aruna Ramasamy, Damien Faux, Vincent Hayward, Malika Auvray, Xavier Job, and Louise Kirsch</i>	
Investigating Movement-Related Tactile Suppression Using Commercial VR Controllers	225
<i>Immo Schuetz, Meaghan McManus, Katja Fiehler, and Dimitris Voudouris</i>	
Estimation of Frictional Force Using the Thermal Images of Target Surface During Stroking	234
<i>Mitsuhiko Shimomura, Masahiro Fujiwara, Yasutoshi Makino, and Hiroyuki Shinoda</i>	
Spatial Resolution of Mesoscopic Shapes Presented by Airborne Ultrasound	243
<i>Zen Somei, Tao Morisaki, Yutaro Toide, Masahiro Fujiwara, Yasutoshi Makino, and Hiroyuki Shinoda</i>	
Haptic Applications	
Vibrotactile Similarity Perception in Crowdsourced and Lab Studies	255
<i>Ramzi Abou Chahine, Dongjae Kwon, Chungman Lim, Gunhyuk Park, and Hasti Seifi</i>	
Perception of Spatialized Vibrotactile Impacts in a Hand-Held Tangible for Virtual Reality	264
<i>Pierre-Antoine Cabaret, Thomas Howard, Claudio Pacchierotti, Marie Babel, and Maud Marchal</i>	
Wearable Haptics in a Modern VR Rehabilitation System: Design Comparison for Usability and Engagement	274
<i>Cristian Camardella, Massimiliano Gabardi, Antonio Frisoli, and Daniele Leonardis</i>	

Perceiving Sequences and Layouts Through Touch 283
Richa Gupta

Whole-Hand Haptics for Mid-air Buttons 292
Martin Maunsbach, Kasper Hornbæk, and Hasti Seifi

Proximity-Based Haptic Feedback for Collaborative Robotic Needle
Insertion 301
*Robin Mieling, Carolin Stapper, Stefan Gerlach, Maximilian Neidhardt,
Sarah Latus, Martin Gromniak, Philipp Breitfeld,
and Alexander Schlaefer*

Fureka: Wearable Tactile Music Toolkit for Children with ASD 310
*Di Qi, Mina Shibasaki, Youichi Kamiyama, Sakiko Tanaka,
Bunsuke Kawasaki, Chisa Mitsuhashi, Yun Suen Pai,
and Kouta Minamizawa*

A Database of Vibratory Signals from Free Haptic Exploration of Natural
Material Textures and Perceptual Judgments (ViPer): Analysis of Spectral
Statistics 319
Matteo Toscani and Anna Metzger

Appendix

Developing a VR Training Environment for Fingers Rehabilitation with
Haptic Feedback 331
Alireza Abbasimoshaei, Ahmed Aly Ibrahim Aly, and T. A. Kern

Impedance Control and Remote Operation of Robotic Wrist
Therapy Systems 334
Jose Pedro Kitajima Borges, Alireza Abbasimoshaei, and T. A. Kern

Feasibility of Smartphone Vibrations as a Sensory Diagnostic Tool 337
*Rachel A. G. Adenekan, Alexis J. Lowber, Bryce N. Huerta,
Allison M. Okamura, Kyle T. Yoshida, and Cara M. Nunez*

Deixis Without Sight: Use of Spatial Demonstratives in the Absence of
Vision 340
Gozdem Arikan and Kenny R. Coventry

A Scalable Haptic Circuit for Multi-digit Grasps 343
*Cristian-Tiberius Axinte, Ciprian Stamate, Robert Gabriel Lupu,
Alexandru Bârleanu, and Georgiana Juravle*

Instrumented Force and Optical Point Tracking to Measure Manual
Brushing in Pleasant Touch 347
J. Michael Bertsch, Zackary Landsman, and Gregory Gerling



Instrumented Object for Finger Pad Imaging During Active Manipulation . . .	351
<i>David Córdoba Bulens, Benoit Delhayé, Philippe Lefèvre, and Stephen Redmond</i>	
Vibrotactile Stimuli are Perceived More Intense at the Front than at the Back of the Torso	354
<i>Bora Celebi, Müge Cavdan, and Knut Drewing</i>	
Imaging Sub-surface Skin Strain Patterns During Fingertip Sliding	358
<i>Giulia Corniani, Zing Lee, Matt J. Carré, Roger Lewis, Benoit P. Delhayé, and Hannes P. Saal</i>	
Sense of Agency Over Hands-free Gestural Control is Modulated by the Timing of Haptic Feedback	362
<i>Calvin Deans-Browne, Antonio Cataldo, William Frier, Hannah Limerick, David Beattie, and Patrick Haggard</i>	
Exploiting a Wearable Extra-Finger for Haptic Applications	366
<i>Mihai Dragusanu, Zubair Iqbal, Domenico Prattichizzo, and Monica Malvezzi</i>	
Finger Pad Deformation Under Torsion	369
<i>Sophie du Bois de Dunilac, David Córdoba Bulens, Philippe Lefèvre, Stephen J. Redmond, and Benoit P. Delhayé</i>	
Haptic Shape Discrimination is Independent of Weight	372
<i>Jessica M. Dukes, Sarah Kiendl, and Jutta Billino</i>	
Human-to-Human Strokes Recordings for Tactile Apparent Motion	376
<i>Basil Duvernoy and Sarah McIntyre</i>	
Between-Tactor Display Using Dynamic Tactile Stimuli	379
<i>Ryo Eguchi, David Vacek, Cole Godzinski, Silvia Curry, Max Evans, and Allison M. Okamura</i>	
Measuring Oddball Responses to Vibrotactile Textures	382
<i>Giulia Esposito, Sylvie Nozaradan, Olivier Collignon, and André Mouraux</i>	
Distinguishable Virtual Haptic Textures to Understand Multisensory Sensation	386
<i>Jenna Fradin and David Gueorguiev</i>	
The Role of the Visuo-Tactile Congruence Between the Size of a Collider and Virtual Contents in the Interactions with Virtual Objects	389
<i>Girondini Matteo, Clerici Monica, Montanaro Massimo, and Gallace Alberto</i>	

Thermal Sensation Display Controlling the Thermal Conductivity of a Surface	394
<i>Johan Gonzalez Sanjuan and Norihisa Miki</i>	
Simulating the Influence of Surface Hardness on the Contact Area Formation for Dry and Moist Finger Skin Contacts	397
<i>Michael Grießer, Thomas Ules, Christian Schipfer, Peter Fuchs, and Dieter P. Gruber</i>	
Embedded 3D Printing: A Cost-effective Development Platform for Tactile Sensors	401
<i>Sonja Groß, Silija Breimann, Sascha Schwarz, Amartya Ganguly, and Sami Haddadin</i>	
Acoustic Finger Force Observation in a Longitudinal Ultrasonic Surface Haptic Device and Its Relation to Friction	404
<i>Diana Angelica Torres, Anis Kaci, Betty Lemaire-Semail, Christophe Giraud-Audine, Frederic Giraud, and Michel Amberg</i>	
Design and Implementation of a Cartesian Impedance Control in a Bilateral Telemanipulation System Using UR10e Robots	408
<i>Ali Hammoud, Fady Youssef, and Thorsten A. Kern</i>	
Mid-air Haptic Biosignal Transfer	412
<i>Daria Hemmerling, Maciej Strojnski, Kamil Kwarciak, Maciej Szymkowski, William Frier, Orestis Georgiou, and Mykola Maksymenko</i>	
Ultrasonic Friction Modulation Modifies the Area of Contact, Not the Shear Strength	416
<i>Nicolas Huloux, Laurence Willemet, and Michaël Wiertlewskin</i>	
Fingertip Friction and Tactile Rating of Wrapping Papers	419
<i>Kim Michèle Jost, Knut Drewing, and Roland Bennewitz</i>	
A Psychological and Behavioral Study on Remote Audio-Visual-Tactile Communication System with Pressure Stimulation	422
<i>Mayuko Ito, Takumi Kuhara, Takuto Matsushashi, Chihiro Hosoda, Keigo Inukai, Junji Watanabe, Kouta Minamizawa, and Yoshihiro Tanaka</i>	
Using Digital Image Correlation to Quantify the Effects of Thin Films on Skin Deformation	426
<i>Anika Kao and Gregory Gerling</i>	
<i>Engineering Haptic Devices</i> 3rd Edition in 2022 in Open-Access	429
<i>Thorsten A. Kern and Alireza Abbasimoshaei</i>	

Wearable Haptic Device for Individuals with Congenital Absence of Proprioception	433
<i>Sreela Kodali, Allison M. Okamura, Thomas C. Bulea, Alexander T. Chesler, and Carsten G. Bönnemann</i>	
Remote High Five: Bidirectional Transmission System for Video, Audio, and Vibrotactile Information Applied for Communication of Athletes with Family; a Case Study	436
<i>Kakagu Komazaki and Junji Watanabe</i>	
Rolling Handle for Hand Motion Guidance and Teleoperation	439
<i>Lisheng Kuang, Maud Marchal, Paolo Robuffo Giordano, and Claudio Pacchierotti</i>	
Is Tactile Shape Coding Invariant Against Small Location Shifts on the Skin?	443
<i>Scinob Kuroki and Shin'ya Nishida</i>	
Precision Grip Discrimination of Object Thickness	447
<i>Alastair J. Loutit, Siddhartha Pande, Naqash Afzal, Pouya Abdollahzadeh, Richard M. Vickery, and Ingvars Birznieks</i>	
Use of Multiple Frequencies of Ultrasound in Midair Haptic Stimulation	452
<i>Saya Mizutani, Shun Suzuki, Atsushi Matsubayashi, Tao Morisaki, Yutaro Toide, Masahiro Fujiwara, Yasutoshi Makino, and Hiroyuki Shinoda</i>	
Presenting Sliding Sensation by Electro-tactile Stimulation	456
<i>Shota Nakayama, Seitaro Kaneko, Mitsuki Manabe, Keigo Ushiyama, Masahiro Miyakami, Akifumi Takahashi, and Hiroyuki Kajimoto</i>	
Uncoupled Stability Dynamic Range for Kelvin- Voigt and Hunt-Crossley Virtual Environments	460
<i>Seanna Oliver, Leonam Pecky, and Keyvan Hashtrudi-Zaad</i>	
Fashion Touch. Surface Haptics in Fashion E-commerce	464
<i>Michela Ornati</i>	
The Influence of Aging on Perceptual Grouping in Haptic Search	468
<i>K. E. Overvliet</i>	
Investigating Haptic Feedback and Arousal for Motor Skill Training in Virtual Reality	472
<i>Unnikrishnan Radhakrishnan, Konstantinos Koumaditis, and Francesco Chinello</i>	
Safe Movement for the Blind Using Localised Haptic Stimulation	475
<i>Jaafar Rammal and Robert Spence</i>	

An Immersive Virtual Paleontology Application	478
<i>Lucas Rodrigues, John Nyakatura, Stefan Zachow, and Johann Habakuk Israel</i>	
Mapping of Vibrotactile Stimuli into a Perceptual Space	482
<i>Rubén Rodríguez, Santiago Cuevas, Jose Lobera, Damián Hernández Lahme, Juan José Zárate, Inés Samengo</i>	
Perception of Guitar Strings on a Flat Visuo-Tactile Display	486
<i>Baptiste Rohou–Claquin, Malika Auvray, Jean-Loïc Le Carrou, and David Gueorguiev</i>	
Pseudo Forces from Asymmetric Vibrations Can Modulate Movement Velocity.	490
<i>Nihar Sabnis, Eline van der Kruk, David Abbink, and Michaël Wiertelowski</i>	
Tactile Friction of UV-Curable Coatings and Its Relation to Surface Hardness	494
<i>Thomas Ules, Michael Grießer, Sandra Schlögl, and Dieter P. Gruber</i>	
Electrotactile Patterns for Single Finger Interactions in VR.	498
<i>Sebastian Vizcay, Panagiotis Kourtesis, Ferran Argelaguet, Claudio Pacchierotti, and Maud Marchal</i>	
Sit-By-Me: A Multi-Sensory Feedback Bench for Social Impromptu Interactions.	501
<i>Keyu Wang, Yun Suen Pai, and Kouta Minamizawa</i>	
ExoSpine: Artificial Muscle-Driven Spine for Posture Correction	504
<i>Yutong Xie, Yun Suen Pai, and Kouta Minamizawa</i>	
Design of Robot End-Effector to Be Used in Studying Actuator- Performance for Vibrotactile Perception in a Telem Manipulation Setup.	507
<i>Fady Youssef, Maximilian Becker, and Thorsten A. Kern</i>	
Author Index	511

Exploiting a Wearable Extra-Finger for Haptic Applications

Mihai Dragusanu¹, Zubair Iqbal¹, Domenico Prattichizzo^{1,2} ,
and Monica Malvezzi¹ 

¹ Department of Information Engineering and Mathematics, University of Siena,
53100 Siena, Italy

`malvezzi@dii.unisi.it`

² Humanoids & Human Centered Mechatronics Research Line, Istituto Italiano
di Tecnologia, Genoa, Italy

Abstract. This extended abstract presents the design of a wearable device for haptic stimulation of hand palms and phalanges. Most of the wearable haptic devices for hand palms are based on a parallel structure, that guarantees good precision and stiffness but presents workspace limitations and encumbrance problems. In this work, we improve the design of a wearable extra-finger, previously designed to augment human hands and to provide assistance for people affected by hand and upper-limb diseases to apply as a haptic device. To employ this device for haptics applications, we provided it an additional adduction/abduction degree of freedom and we modified the fingertip/end-effector to include a micro force sensor.

1 Introduction

Human augmentation by means of supernumerary robotic limbs (SRLs) represents a recent and lively research topic [1]. SRLs are developed to allow humans to perform complex actions with increased strength and precision, and also to enlarge the human workspace. Our research group has been involved in particular in the development of supernumerary extra-fingers [2, 3]. Adding a single or double extra robotic finger can improve the grasping capabilities of the human hand and its dexterity even in complex actions.

In this work we propose to exploit supernumerary extra fingers as wearable haptic devices for cutaneous stimuli of hand palm and phalanges. Although the hand is one of the primary interfaces between humans and the surrounding environment, most of the haptic devices that return tactile stimuli are focused on the fingers [4], while fewer of them are developed specifically for the palm. Most of the wearable haptics devices developed for hand palm are based on parallel mechanisms, i.e. mechanical systems using multiple serial chains (typically varying from 3 to 6) to support a single platform, or end-effector [5–7]. One of the main drawbacks of parallel mechanisms is that their workspace, i.e. the set of possible configurations that can be reached by the end effector is rather limited,

and in haptics context this means that a limited part of the hand can be stimulated. Serial mechanisms, on the other hand, typically are more flexible and less precise than parallel ones, but their open structure allows to reach a wider workspace.

2 The Improvement of the Sixth Finger

As mentioned in the previous section, in this work we improved the wearable extra finger developed in [3, 8] to exploit it in haptic applications.

The robotic extra finger [8] has a modular structure, each module is composed of a rigid part realized in ABS (Acrylonitrile Butadiene Styrene, ABSPlus, Stratasys, USA) and flexible part, made of TPU (thermoplastic polyurethane, Lulzbot, USA). We selected TPU in particular because the high elongation of this material allows for repeated movement and impact without wear or cracking proving. Seven modules were employed in order to achieve a length of the finger similar to the average size of human hand. The robotic extra finger is tendon-driven and is actuated by only one motor, providing the flexion movement.

To exploit the extra finger in haptic applications, we increased its workspace by providing it the adduction/abduction motion, by connecting the proximal module to a platform orientable by means of a gear system. To reduce the encumbrance on the wrist, the motor was substituted by a linear actuator. Furthermore the distal module was sensorised with a microforce sensor, necessary to

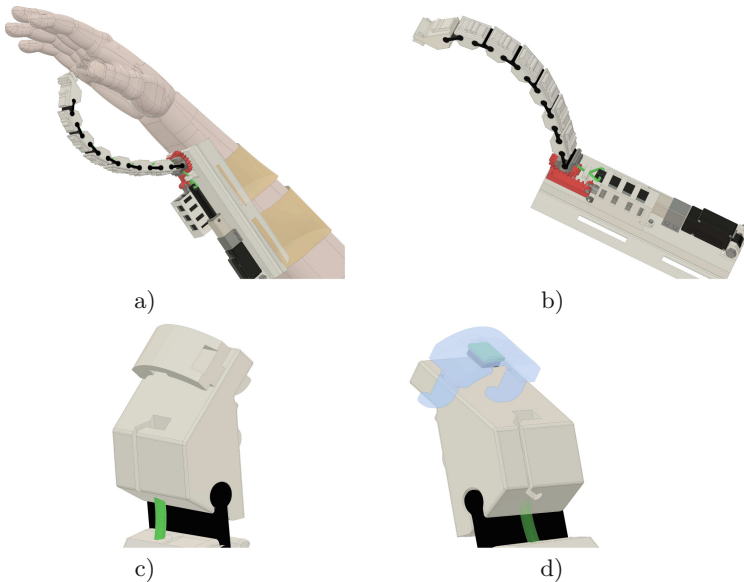


Fig. 1. (a) CAD model of the wearable extra finger exploited for haptic applications, worn by the user. (b) CAD model of the wearable extra finger, showing the actuation. (c) Fingertip module. (d) Sensing elements in the fingertip module.

control haptic interaction with human hand. CAD model of the proposed device is shown in Fig. 1. Furthermore, the stiffness of the flexible elements connecting finger phalanges has been calculated using the procedure proposed in [8] so that when the actuator pull the tendon, the extra-finger flexes by keeping the distal phalanx approximately perpendicular to hand palm.

3 Future Works

The device is currently in the prototyping phase. A first set of experimental tests will be aimed at verifying its functional characteristics, in particular, we will identify the part of the hand that can be stimulated with the device and the corresponding force that can be applied. Then in a second experimental phase we will compare it with the device presented in [7]. Then, users studies will be carried out to assess device usability in VR and AR contexts.

References

1. Prattichizzo, D., et al.: Human augmentation by wearable supernumerary robotic limbs: review and perspectives. *Progress Biomed. Eng.* **3**(4), 042005 (2021)
2. Prattichizzo, D., Salvietti, G., Chinello, F., Malvezzi, M.: An object-based mapping algorithm to control wearable robotic extra-fingers. In: 2014 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1563–1568. IEEE (2014)
3. Malvezzi, M., Iqbal, Z., Valigi, M.C., Pozzi, M., Prattichizzo, D., Salvietti, G.: Design of multiple wearable robotic extra fingers for human hand augmentation. *Robotics* **8**(4), 102 (2019)
4. Prattichizzo, D., Chinello, F., Pacchierotti, C., Malvezzi, M.: Towards wearability in fingertip haptics: a 3-DoF wearable device for cutaneous force feedback. *IEEE Trans. Haptics* **6**(4), 506–516 (2013)
5. Trinitatova, D., Tsetserukou, D.: TouchVR: a wearable haptic interface for VR aimed at delivering multi-modal stimuli at the user’s palm. In: SIGGRAPH Asia 2019 XR, pp. 42–43 (2019)
6. Minamizawa, K., Kamuro, S., Kawakami, N., Tachi, S.: A palm-worn haptic display for bimanual operations in virtual environments. In: Ferre, M. (ed.) *EuroHaptics 2008*. LNCS, vol. 5024, pp. 458–463. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-69057-3_59
7. Dragusanu, M., Villani, A., Prattichizzo, D., Malvezzi, M.: Design of a wearable haptic device for hand palm cutaneous feedback. *Front. Robot. AI* **8** (2021)
8. Salvietti, G., Hussain, I., Malvezzi, M., Prattichizzo, D.: Design of the passive joints of underactuated modular soft hands for fingertip trajectory tracking. *IEEE Robot. Autom. Lett.* **2**(4), 2008–2015 (2017)