

Vincent G. Duffy (Ed.)

LNCS 14028

Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management

14th International Conference, DHM 2023

Held as Part of the 25th HCI International Conference, HCII 2023

Copenhagen, Denmark, July 23–28, 2023

Proceedings, Part I

1
Part I



 Springer

MOREMEDIA 

Lecture Notes in Computer Science

14028


Founding Editors

Gerhard Goos
Juris Hartmanis

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*

The series Lecture Notes in Computer Science (LNCS), including its subseries Lecture Notes in Artificial Intelligence (LNAI) and Lecture Notes in Bioinformatics (LNBI), has established itself as a medium for the publication of new developments in computer science and information technology research, teaching, and education.

LNCS enjoys close cooperation with the computer science R & D community, the series counts many renowned academics among its volume editors and paper authors, and collaborates with prestigious societies. Its mission is to serve this international community by providing an invaluable service, mainly focused on the publication of conference and workshop proceedings and postproceedings. LNCS commenced publication in 1973.

Vincent G. Duffy
Editor

Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management

14th International Conference, DHM 2023
Held as Part of the 25th HCI International Conference, HCII 2023
Copenhagen, Denmark, July 23–28, 2023
Proceedings, Part I

Editor

Vincent G. Duffy
Purdue University
West Lafayette, IN, USA

ISSN 0302-9743

ISSN 1611-3349 (electronic)

Lecture Notes in Computer Science

ISBN 978-3-031-35740-4

ISBN 978-3-031-35741-1 (eBook)

<https://doi.org/10.1007/978-3-031-35741-1>

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Switzerland AG 2023

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

Foreword

Human-computer interaction (HCI) is acquiring an ever-increasing scientific and industrial importance, as well as having more impact on people's everyday lives, as an ever-growing number of human activities are progressively moving from the physical to the digital world. This process, which has been ongoing for some time now, was further accelerated during the acute period of the COVID-19 pandemic. The HCI International (HCII) conference series, held annually, aims to respond to the compelling need to advance the exchange of knowledge and research and development efforts on the human aspects of design and use of computing systems.

The 25th International Conference on Human-Computer Interaction, HCI International 2023 (HCII 2023), was held in the emerging post-pandemic era as a 'hybrid' event at the AC Bella Sky Hotel and Bella Center, Copenhagen, Denmark, during July 23–28, 2023. It incorporated the 21 thematic areas and affiliated conferences listed below.

A total of 7472 individuals from academia, research institutes, industry, and government agencies from 85 countries submitted contributions, and 1578 papers and 396 posters were included in the volumes of the proceedings that were published just before the start of the conference, these are listed below. The contributions thoroughly cover the entire field of human-computer interaction, addressing major advances in knowledge and effective use of computers in a variety of application areas. These papers provide academics, researchers, engineers, scientists, practitioners and students with state-of-the-art information on the most recent advances in HCI.

The HCI International (HCII) conference also offers the option of presenting 'Late Breaking Work', and this applies both for papers and posters, with corresponding volumes of proceedings that will be published after the conference. Full papers will be included in the 'HCII 2023 - Late Breaking Work - Papers' volumes of the proceedings to be published in the Springer LNCS series, while 'Poster Extended Abstracts' will be included as short research papers in the 'HCII 2023 - Late Breaking Work - Posters' volumes to be published in the Springer CCIS series.

I would like to thank the Program Board Chairs and the members of the Program Boards of all thematic areas and affiliated conferences for their contribution towards the high scientific quality and overall success of the HCI International 2023 conference. Their manifold support in terms of paper reviewing (single-blind review process, with a minimum of two reviews per submission), session organization and their willingness to act as goodwill ambassadors for the conference is most highly appreciated.

This conference would not have been possible without the continuous and unwavering support and advice of Gavriel Salvendy, founder, General Chair Emeritus, and Scientific Advisor. For his outstanding efforts, I would like to express my sincere appreciation to Abbas Moallem, Communications Chair and Editor of HCI International News.

HCI International 2023 Thematic Areas and Affiliated Conferences

Thematic Areas

- HCI: Human-Computer Interaction
- HIMI: Human Interface and the Management of Information

Affiliated Conferences

- EPCE: 20th International Conference on Engineering Psychology and Cognitive Ergonomics
- AC: 17th International Conference on Augmented Cognition
- UAHCI: 17th International Conference on Universal Access in Human-Computer Interaction
- CCD: 15th International Conference on Cross-Cultural Design
- SCSM: 15th International Conference on Social Computing and Social Media
- VAMR: 15th International Conference on Virtual, Augmented and Mixed Reality
- DHM: 14th International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management
- DUXU: 12th International Conference on Design, User Experience and Usability
- C&C: 11th International Conference on Culture and Computing
- DAPI: 11th International Conference on Distributed, Ambient and Pervasive Interactions
- HCIBGO: 10th International Conference on HCI in Business, Government and Organizations
- LCT: 10th International Conference on Learning and Collaboration Technologies
- ITAP: 9th International Conference on Human Aspects of IT for the Aged Population
- AIS: 5th International Conference on Adaptive Instructional Systems
- HCI-CPT: 5th International Conference on HCI for Cybersecurity, Privacy and Trust
- HCI-Games: 5th International Conference on HCI in Games
- MobiTAS: 5th International Conference on HCI in Mobility, Transport and Automotive Systems
- AI-HCI: 4th International Conference on Artificial Intelligence in HCI
- MOBILE: 4th International Conference on Design, Operation and Evaluation of Mobile Communications

List of Conference Proceedings Volumes Appearing Before the Conference

1. LNCS 14011, Human-Computer Interaction: Part I, edited by Masaaki Kurosu and Ayako Hashizume
2. LNCS 14012, Human-Computer Interaction: Part II, edited by Masaaki Kurosu and Ayako Hashizume
3. LNCS 14013, Human-Computer Interaction: Part III, edited by Masaaki Kurosu and Ayako Hashizume
4. LNCS 14014, Human-Computer Interaction: Part IV, edited by Masaaki Kurosu and Ayako Hashizume
5. LNCS 14015, Human Interface and the Management of Information: Part I, edited by Hirohiko Mori and Yumi Asahi
6. LNCS 14016, Human Interface and the Management of Information: Part II, edited by Hirohiko Mori and Yumi Asahi
7. LNAI 14017, Engineering Psychology and Cognitive Ergonomics: Part I, edited by Don Harris and Wen-Chin Li
8. LNAI 14018, Engineering Psychology and Cognitive Ergonomics: Part II, edited by Don Harris and Wen-Chin Li
9. LNAI 14019, Augmented Cognition, edited by Dylan D. Schmorow and Cali M. Fidopiastis
10. LNCS 14020, Universal Access in Human-Computer Interaction: Part I, edited by Margherita Antona and Constantine Stephanidis
11. LNCS 14021, Universal Access in Human-Computer Interaction: Part II, edited by Margherita Antona and Constantine Stephanidis
12. LNCS 14022, Cross-Cultural Design: Part I, edited by Pei-Luen Patrick Rau
13. LNCS 14023, Cross-Cultural Design: Part II, edited by Pei-Luen Patrick Rau
14. LNCS 14024, Cross-Cultural Design: Part III, edited by Pei-Luen Patrick Rau
15. LNCS 14025, Social Computing and Social Media: Part I, edited by Adela Coman and Simona Vasilache
16. LNCS 14026, Social Computing and Social Media: Part II, edited by Adela Coman and Simona Vasilache
17. LNCS 14027, Virtual, Augmented and Mixed Reality, edited by Jessie Y. C. Chen and Gino Fragomeni
18. LNCS 14028, Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management: Part I, edited by Vincent G. Duffy
19. LNCS 14029, Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management: Part II, edited by Vincent G. Duffy
20. LNCS 14030, Design, User Experience, and Usability: Part I, edited by Aaron Marcus, Elizabeth Rosenzweig and Marcelo Soares
21. LNCS 14031, Design, User Experience, and Usability: Part II, edited by Aaron Marcus, Elizabeth Rosenzweig and Marcelo Soares

22. LNCS 14032, Design, User Experience, and Usability: Part III, edited by Aaron Marcus, Elizabeth Rosenzweig and Marcelo Soares
23. LNCS 14033, Design, User Experience, and Usability: Part IV, edited by Aaron Marcus, Elizabeth Rosenzweig and Marcelo Soares
24. LNCS 14034, Design, User Experience, and Usability: Part V, edited by Aaron Marcus, Elizabeth Rosenzweig and Marcelo Soares
25. LNCS 14035, Culture and Computing, edited by Matthias Rauterberg
26. LNCS 14036, Distributed, Ambient and Pervasive Interactions: Part I, edited by Norbert Streitz and Shin'ichi Konomi
27. LNCS 14037, Distributed, Ambient and Pervasive Interactions: Part II, edited by Norbert Streitz and Shin'ichi Konomi
28. LNCS 14038, HCI in Business, Government and Organizations: Part I, edited by Fiona Fui-Hoon Nah and Keng Siau
29. LNCS 14039, HCI in Business, Government and Organizations: Part II, edited by Fiona Fui-Hoon Nah and Keng Siau
30. LNCS 14040, Learning and Collaboration Technologies: Part I, edited by Panayiotis Zaphiris and Andri Ioannou
31. LNCS 14041, Learning and Collaboration Technologies: Part II, edited by Panayiotis Zaphiris and Andri Ioannou
32. LNCS 14042, Human Aspects of IT for the Aged Population: Part I, edited by Qin Gao and Jia Zhou
33. LNCS 14043, Human Aspects of IT for the Aged Population: Part II, edited by Qin Gao and Jia Zhou
34. LNCS 14044, Adaptive Instructional Systems, edited by Robert A. Sottolare and Jessica Schwarz
35. LNCS 14045, HCI for Cybersecurity, Privacy and Trust, edited by Abbas Moallem
36. LNCS 14046, HCI in Games: Part I, edited by Xiaowen Fang
37. LNCS 14047, HCI in Games: Part II, edited by Xiaowen Fang
38. LNCS 14048, HCI in Mobility, Transport and Automotive Systems: Part I, edited by Heidi Krömker
39. LNCS 14049, HCI in Mobility, Transport and Automotive Systems: Part II, edited by Heidi Krömker
40. LNAI 14050, Artificial Intelligence in HCI: Part I, edited by Helmut Degen and Stavroula Ntoa
41. LNAI 14051, Artificial Intelligence in HCI: Part II, edited by Helmut Degen and Stavroula Ntoa
42. LNCS 14052, Design, Operation and Evaluation of Mobile Communications, edited by Gavriel Salvendy and June Wei
43. CCIS 1832, HCI International 2023 Posters - Part I, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy
44. CCIS 1833, HCI International 2023 Posters - Part II, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy
45. CCIS 1834, HCI International 2023 Posters - Part III, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy
46. CCIS 1835, HCI International 2023 Posters - Part IV, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy

47. CCIS 1836, HCI International 2023 Posters - Part V, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy

<https://2023.hci.international/proceedings>



Preface

Software representations of humans, including aspects of anthropometry, biometrics, motion capture and prediction, as well as cognition modeling, are known as Digital Human Models (DHM), and are widely used in a variety of complex application domains where it is important to foresee and simulate human behavior, performance, safety, health and comfort. Automation depicting human emotion, social interaction and functional capabilities can also be modeled to support and assist in predicting human response in real-world settings. Such domains include medical and nursing applications, work, education and learning, ergonomics and design, as well as safety and risk management.

The 14th Digital Human Modeling & Applications in Health, Safety, Ergonomics & Risk Management (DHM) Conference, an affiliated conference of the HCI International Conference 2023, encouraged papers from academics, researchers, industry and professionals, on a broad range of theoretical and applied issues related to Digital Human Modeling and its applications.

The research papers contributed to this year's volumes span across different fields that fall within the scope of the DHM Conference. The study of DHM issues in various application domains has yielded works emphasizing human factors and ergonomics based on human models, novel approaches in healthcare, and the application of Artificial Intelligence in medicine. Applications of interest are shown across many industries. Job design and productivity, robotics and intelligent systems are among the human-technology modeling and results reporting efforts this year.

Two volumes of the HCII 2023 proceedings are dedicated to this year's edition of the DHM Conference. The first volume focuses on topics related to human factors and ergonomics, job design and human productivity, as well as interaction with robots and exoskeletons. The second volume focuses on topics related to digital health, IoT and AI in medicine and healthcare, as well as modeling complex human behavior and phenomena.

Papers of these volumes are included for publication after a minimum of two single-blind reviews from the members of the DHM Program Board or, in some cases, from members of the Program Boards of other affiliated conferences. I would like to thank all of them for their invaluable contribution, support and efforts.

July 2023

Vincent G. Duffy

14th International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management (DHM 2023)

Program Board Chair: **Vincent G. Duffy**, *Purdue University, USA*

- Karthik Adapa, *UNC-Chapel Hill, USA*
- Giuseppe Andreoni, *Politecnico di Milano, Italy*
- Mária Babicsné Horváth, *Budapest University of Technology and Economics, Hungary*
- Angelos Barmpoutis, *University of Florida, USA*
- André Calero Valdez, *University of Lübeck, Germany*
- Yaqin Cao, *Anhui Polytechnic University, P.R. China*
- Damien Chablat, *CNRS/LS2N, France*
- Anirban Chowdhury, *NMIMS University, India*
- H. Onan Demirel, *Oregon State University, USA*
- Yi Ding, *Anhui Polytechnic University, P.R. China*
- Manish K. Dixit, *Texas A&M University, USA*
- Lucia Donatelli, *Saarland University, Germany*
- Martin Fleischer, *Technical University of Munich, Germany*
- Martin Fränzle, *Oldenburg University, Germany*
- RongRong Fu, *East China University of Science and Technology, P.R. China*
- Afzal Godil, *NIST, USA*
- Wenbin Guo, *University of Florida, USA*
- Jaana Hallamaa, *University of Helsinki, Finland*
- Sogand Hasanzadeh, *Purdue University, USA*
- Nicola Helfer, *KAN - Commission for Occupational Health and Safety and Standardization, Germany*
- Sandy Ingram, *University of Applied Sciences of Western Switzerland, Switzerland*
- Genett Isabel Jimenez Delgado, *Institución Universitaria de Barranquilla IUB, Colombia*
- Taina Kalliokoski, *University of Helsinki, Finland*
- Sougata Karmakar, *Indian Institute of Technology Guwahati, India*
- Najmeh Khalili-Mahani, *Concordia University, Canada*
- Steffi Kohl, *Zuyd University of Applied Sciences, The Netherlands*
- Nicola Francesco Lopomo, *Università degli Studi di Brescia, Italy*
- Alexander Mehler, *Goethe University Frankfurt, Germany*
- Manivannan Muniyandi, *IIT Madras, India*
- Peter Nickel, *Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), Germany*
- Miguel Ortiz-Barrios, *Universidad de la Costa CUC, Colombia*
- Thanewer Patel, *North Eastern Regional Institute of Science and Technology, India*
- Manikam Pillay, *RESMEERTS, Australia*

- James Pustejovsky, *Brandeis University, USA*
- Qing-Xing Qu, *Northeastern University, P.R. China*
- Caterina Rizzi, *University of Bergamo, Italy*
- Deep Seth, *Mahindra University, India*
- Thitirat Siriborvornratanakul, *National Institute of Development Administration, Thailand*
- Beatriz Sousa Santos, *University of Aveiro, Portugal*
- Debadutta Subudhi, *IIT Madras, India*
- Youchao Sun, *Nanjing University of Aeronautics and Astronautics, P.R. China*
- Zhengtang Tan, *Human Normal University, P.R. China*
- Leonor Teixeira, *University of Aveiro, Portugal*
- Renran Tian, *IUPUI, USA*
- Joseph Timoney, *Maynooth University, Ireland*
- Alexander Trende, *German Aerospace Center (DLR), Germany*
- Dustin van der Haar, *University of Johannesburg, South Africa*
- Kuan Yew Wong, *Universiti Teknologi Malaysia, Malaysia*
- Shuping Xiong, *Korea Advanced Institute of Science and Technology, South Korea*
- James Yang, *Texas Tech University, USA*
- Azeema Yaseen, *Maynooth University, Ireland*
- Yulin Zhao, *Guangdong University of Technology, P.R. China*

The full list with the Program Board Chairs and the members of the Program Boards of all thematic areas and affiliated conferences of HCII2023 is available online at:

<http://www.hci.international/board-members-2023.php>



HCI International 2024 Conference

The 26th International Conference on Human-Computer Interaction, HCI International 2024, will be held jointly with the affiliated conferences at the Washington Hilton Hotel, Washington, DC, USA, June 29 – July 4, 2024. It will cover a broad spectrum of themes related to Human-Computer Interaction, including theoretical issues, methods, tools, processes, and case studies in HCI design, as well as novel interaction techniques, interfaces, and applications. The proceedings will be published by Springer. More information will be made available on the conference website: <http://2024.hci.international/>.

General Chair

Prof. Constantine Stephanidis

University of Crete and ICS-FORTH

Heraklion, Crete, Greece

Email: general_chair@hci2024.org

<https://2024.hci.international/>



Contents – Part I

Human Factors and Ergonomics

| | |
|---|-----|
| Simulation of Cable Driven Elbow Exosuit in Matlab | 3 |
| <i>Sreejan Alapati, Deep Seth, and Yannick Aoustin</i> | |
| Experimental Research on Ergonomics Evaluation of HMDs | 14 |
| <i>Kai An, Xu Wu, Chongchong Miao, Lin Ding, and Guoqiang Sun</i> | |
| A Platform for Long-Term Analysis and Reporting of Sitting Posture | 24 |
| <i>Rafael de Pinho André, Almir Fonseca, Kayo Yokoyama, Lucas Westfal, Luis Laguardia, and Marcelo de Souza</i> | |
| Design and Development of a Novel Wearable System for Assessing the Biomechanical and Psychological Risk of the Healthcare Worker | 35 |
| <i>Carla Dei, Giulia Stevanoni, Emilia Biffi, Fabio Storm, Nicola Francesco Lopomo, Paolo Perego, and Giuseppe Andreoni</i> | |
| The Impact of Smart Glasses on Commissioning Efficiency Depends on the Display Device Used | 48 |
| <i>Daniel Friemert, Martin Laun, Christopher Braun, Nicolai Leuthner, Rolf Ellegast, Christoph Schiefer, Volker Harth, Claudia Terschüren, Kiros Karamanidis, and Ulrich Hartmann</i> | |
| Digital Twin Modelling for Human-Centered Ergonomic Design | 58 |
| <i>Micah Wilson George, Nandini Gaikwad, Vincent G. Duffy, and Allen G. Greenwood</i> | |
| Wearables and Mixed Reality in Applied Ergonomics: A Literature Review | 70 |
| <i>Xiyun Hu, Runlin Duan, Ziyi Liu, and Vincent G. Duffy</i> | |
| Enhancing Ergonomic Design Process with Digital Human Models for Improved Driver Comfort in Space Environment | 87 |
| <i>Md Tariqul Islam, Kamelia Sepanloo, Ronak Velluvakkandy, Andre Luebke, and Vincent G. Duffy</i> | |
| Improving Facility Layout Using an Ergonomics and Simulation-Based Approach | 102 |
| <i>Krittika J. Iyer, Nandini Narula, Marlyn Binu, and Vincent G. Duffy</i> | |

| | |
|---|-----|
| A Smart Sensor Suit (SSS) to Assess Cognitive and Physical Fatigue with Machine Learning | 120 |
| <i>Ashish Jaiswal, Mohammad Zaki Zadeh, Aref Hebri, Ashwin Ramesh Babu, and Fillia Makedon</i> | |
| Application of Ramsis Digital Human Modeling to Human Factors in Space ... | 135 |
| <i>Kevin Jin, Mackenzie Richards, and Kevin Lee</i> | |
| Ergonomics Research of Domestic Vehicle Cab Central Control System Based on Entropy Method | 147 |
| <i>Qingchen Li and Yongxin Wu</i> | |
| Investigating the Time Dependency of Elbow Flexion Angle Variations in Real and Virtual Grabbing Tasks Using Statistical Parametric Mapping | 162 |
| <i>Nils Mayat, Stella Adam, Mahmood Alkawarit, Anika Weber, Jan P. Vox, Krzysztof Izdebski, Thomas Schüller, Karen Insa Wolf, and Daniel Friemert</i> | |
| An Experimental Study of the Psychological Effects of Vision Loss for Practical Application to Windowless Cockpits | 175 |
| <i>Yuki Mekata, Nagisa Hashimoto, and Miwa Nakanishi</i> | |
| Human Factors in Interface Design of Electronic Control Systems for Mechanical Equipment in Stage and Studio Automation | 184 |
| <i>Peter Nickel</i> | |
| Quantitative Characterization of Upper Limb Intensity and Symmetry of Use in Healthcare Workers Using Wrist-Worn Accelerometers | 194 |
| <i>Micaela Porta, Giulia Casu, Bruno Leban, and Massimiliano Pau</i> | |
| Human Ergonomic Assessment Within “Industry 5.0” Workplace: Do Standard Observational Methods Correlate with Kinematic-Based Index in Reaching Tasks? | 205 |
| <i>Emilia Scalona, Doriana De Marco, Pietro Avanzini, Maddalena Fabbri Destro, Giuseppe Andreoni, and Nicola Francesco Lopomo</i> | |
| Challenges for Standardized Ergonomic Assessments by Digital Human Modeling | 215 |
| <i>Kerstin Schmidt, Paul Schmidt, and Anna Schlenz</i> | |
| Assessing Ergonomics on IPS IMMA Family of Manikins | 242 |
| <i>Manuela Vargas, Maria Pia Cavatorta, Valerio Cibrario, Enrica Bosani, and Meike Schaub</i> | |

| | |
|---|-----|
| Improving Ergonomic Training Using Augmented Reality Feedback | 256 |
| <i>Diego Vicente, Mario Schwarz, and Gerrit Meixner</i> | |
| BGHW Warehouse Simulation – Virtual Reality Supports Prevention of Slip, Trip and Fall (STF) Accidents | 276 |
| <i>Christoph Wetzel, Andy Lungfiel, and Peter Nickel</i> | |
| The Low Back Fatigue Research Based on Controlled Sedentary Driving Tasks | 290 |
| <i>Xiang Wu, Tianfeng Xu, Yeqi Wu, Ziyang Dong, Xinran Liu, Xiangyu Liu, and Li Xu</i> | |
| An Experimental Study of the Comfort of Stroke Rehabilitation Gloves Based on ANSYS | 303 |
| <i>Yanmin Xue, Liangliang Shi, Qing Liu, and Suihuai Yu</i> | |
| Job Design and Human Productivity | |
| Development and Evaluation of a Knowledge-Based Cyber-Physical Production System to Support Industrial Set-Up Processes Considering Ergonomic and User-Centered Aspects | 317 |
| <i>Nils Darwin Abele, Sven Hoffmann, Aparecido Fabiano Pinatti De Carvalho, Marcus Schweitzer, Volker Wulf, and Karsten Kluth</i> | |
| Evaluating Domain-Independent Small Talk Conversations to Improve Clinical Communication Interaction for Human and Machine | 330 |
| <i>Chloe Aguilar, Muhammad Amith, Lu Tang, Jane Hamilton, Lara S. Savas, Danniell Rhee, Tazrin Khan, and Cui Tao</i> | |
| The Impacts of Covid-19 Pandemic on Nursing Workflow in a Medical ICU ... | 344 |
| <i>Vitor de Oliveira Vargas, Jung Hyup Kim, Alireza Kasaie Sharifi, and Laurel Despina</i> | |
| Human Factors in Manufacturing: A Systematic Literature Review | 355 |
| <i>Fabio Garofalo and Passawit Puangseree</i> | |
| Pre-defined Emergencies on Demand: Simulation-Based Analysis of Information Processing in Emergency Dispatching | 368 |
| <i>Marthe Gruner, Tim Schrills, and Thomas Franke</i> | |
| Design Requirements for Working with Mobile Smart devices—a Scoping Review | 383 |
| <i>Germaine Haase, Kristin Gilbert, and Ulrike Pietrzyk</i> | |

| | |
|---|-----|
| Implementation of Lean Six Sigma to Improve the Quality and Productivity in Textile Sector: A Case Study | 395 |
| <i>Genett Jiménez-Delgado, Iván Quintero-Ariza, Jeremy Romero-Gómez, Carlos Montero-Bula, Edgar Rojas-Castro, Gilberto Santos, José Carlos Sá, Luz Londoño-Lara, Hugo Hernández-Palma, and Leonardo Campis-Freyle</i> | |
| Simulation-Based Training in the Manufacturing Industry: A Suggested Quick Assessment | 413 |
| <i>Tiantian Li and Kevin J. Kaufman-Ortiz</i> | |
| Analysis of Work-Flow Design Related to Aspects of Productivity and Ergonomics | 429 |
| <i>Sindhu Meenakshi and Santhosh Kumar Balasankar</i> | |
| Quality of Experience and Mental Energy Use of Cobot Workers in Manufacturing Enterprises | 444 |
| <i>Fabio Alexander Storm, Luca Negri, Claudia Carissoli, Alberto Peña Fernández, Carla Dei, Marta Bassi, Daniel Berckmans, and Antonella Delle Fave</i> | |
| Something Old, Something New, Something Inspired by Deep Blue?: A Scoping Review on the Digital Transformation of Office and Knowledge Work from the Perspective of OSH | 459 |
| <i>Patricia Tegmeier, Jan Terhoeven, and Sascha Wischniewski</i> | |
| Description of Sequential Risky Decision-Making Choices in Human-Machine Teams Using Eye-Tracking and Decision Tree | 478 |
| <i>Wei Xiong, Chen Wang, and Liang Ma</i> | |
| Interacting with Robots and Exoskeletons | |
| Introduction of a Cobot as Intermittent Haptic Contact Interfaces in Virtual Reality | 497 |
| <i>V. K Guda, S. Mugisha, C. Chevallereau, and D. Chablat</i> | |
| The Efficiency of Augmented Pointing with and Without Speech in a Collaborative Virtual Environment | 510 |
| <i>Oliver Herbort and Lisa-Marie Krause</i> | |
| Does the Form of Attachment Have an Impact on Occupational Thermal Comfort? A Study on the Spinal Exoskeleton | 525 |
| <i>Yang Liu, Yanmin Xue, Chang Ge, Yihui Zhou, and Wen Yan</i> | |

| | |
|--|------------|
| <p>A Multimodal Data Model for Simulation-Based Learning with Va.Si.Li-Lab</p> <p><i>Alexander Mehler, Mevlüt Bağci, Alexander Henlein, Giuseppe Abrami, Christian Spiekermann, Patrick Schrottenbacher, Maxim Konca, Andy Lücking, Juliane Engel, Marc Quintino, Jakob Schreiber, Kevin Saukel, and Olga Zlatkin-Troitschanskaia</i></p> | <p>539</p> |
| <p>TWINMED T-SHIRT, a Smart Wearable System for ECG and EMG Monitoring for Rehabilitation with Exoskeletons</p> <p><i>Paolo Perego, Roberto Sironi, Emanuele Gruppioni, and Giuseppe Andreoni</i></p> | <p>566</p> |
| <p>Evaluating Multimodal Behavior Schemas with VoxWorld</p> <p><i>Christopher Tam, Richard Brutti, Kenneth Lai, and James Pustejovsky</i></p> | <p>578</p> |
| <p>Robust Motion Recognition Using Gesture Phase Annotation</p> <p><i>Hannah VanderHoeven, Nathaniel Blanchard, and Nikhil Krishnaswamy</i></p> | <p>592</p> |
| <p>Short Intervention of Self-study-Videos in a Safety Engineering Learning Arrangement: An Investigation of Effects on Learning Performance and Motivation</p> <p><i>Julia Waldorf, Florian Hafner, Marina Bier, Nina Hanning, Lucia Maletz, Carolin Frank, and Anke Kahl</i></p> | <p>609</p> |
| <p>An AI-Based Action Detection UAV System to Improve Firefighter Safety</p> <p><i>Hong Wang, Yuan Feng, Xu Huang, and Wenbin Guo</i></p> | <p>632</p> |
| <p>The Effect of Transparency on Human-Exoskeleton Interaction</p> <p><i>Yilin Wang, Jing Qiu, Hong Cheng, Xiuying Hu, Peng Xu, Jingming Hou, and Hongqin Xie</i></p> | <p>642</p> |
| <p>Author Index</p> | <p>653</p> |

Contents – Part II

Digital Health

| | |
|---|-----|
| Computational Support to Apply Eladeb Auto-Evaluation in Multiple Platforms | 3 |
| <i>Adriano Mendes Borges, Walbert Cunha Monteiro, Vinicius Favacho Queiroz, Kelly Vale Pinheiro, Thiago Augusto Soares de Sousa, and Bianchi Serique Meiguins</i> | |
| Let's Start Tomorrow - Bridging the Intention Behavior Gap Using Fitness Apps | 20 |
| <i>Laura Burbach, Rachel Ganser, Luisa Vervier, Martina Ziefle, and André Calero Valdez</i> | |
| A Study on the Service Design of Self-health Management for Adolescents with Asthma Based on Persuasive Technology | 38 |
| <i>Zhe Hu and Yi Li</i> | |
| Demystifying the Role of Digital Leadership in the Healthcare Industry: A Systematic Review Towards the Development of a Digital Leadership Framework in the Healthcare Industry | 49 |
| <i>Muzammil Hussain, Isra Sarfraz, and Abhishek Sharma</i> | |
| Promote or Restrict? A Co-design Practice of a Palliative Care Information Management System in China | 65 |
| <i>Yue Jiang, Jing Chen, Qi Chen, and Long Liu</i> | |
| Motivation Enhancement Design for Individual Exercise Habits Based on Multimodal Physiological Signals | 77 |
| <i>Xiangyu Liu, Di Zhang, Jiayuan Lu, Bin Shi, Lv Ding, Yingjie Huang, Ke Miao, and Hao Tang</i> | |
| Designing Relational AI-Powered Digital Health Coaching for Chronic Disease Prevention and Management | 88 |
| <i>Yunmin Oh, Kika Arias, Lisa Auster-Gussman, and Sarah Graham</i> | |
| A Hybrid Multi-criteria Framework for Evaluating the Performance of Clinical Labs During the Covid-19 Pandemic | 104 |
| <i>Miguel Ortiz-Barrios, Andrea Espeleta-Aris, Genett Jiménez-Delgado, Helder Jose Celani-De Souza, Jonas Santana-de Oliveira, Alexandros Konios, Leonardo Campis-Freyte, and Eduardo Navarro-Jimenez</i> | |

| | |
|--|-----|
| The Role of Social Networks When Using Digital Health Interventions for Multimorbidity | 123 |
| <i>Sara Polak, Cora van Leeuwen, Myriam Sillevs Smitt, Julie Doyle, Suzanne Cullen-Smith, and An Jacobs</i> | |
| Applying the Trajectories Conceptual Framework: A Case Study of an IoT Health Data Monitoring Application | 138 |
| <i>Elizabeth Reisher, Soundarya Jonnalagadda, and Ann Fruhling</i> | |
| Multidimensional Data Integration and Analysis for Youth Health Care During the Covid-19 Pandemic | 154 |
| <i>Jianlun Wu, Yaping Ye, Yuxi Li, Ruichen Cong, Yishan Bian, Yuerong Chen, Kiichi Tago, Shoji Nishimura, Atsushi Ogihara, and Qun Jin</i> | |
| Design for Shoulder and Neck Pain Based on Yoga Asanas Practice | 169 |
| <i>Yeqi Wu, Ziyang Dong, Xinran Liu, Xiang Wu, Tianfeng Xu, Xiangyu Liu, and Li Xu</i> | |
| Proposal for Family Health Management Service Based on Personal Medical and Lifelog Data, and Genetic Information | 185 |
| <i>Jae Sun Yi and Mingyeong Kim</i> | |
| An Interactive Design Solution for Sleep Persuasion Based on Health Risk Visualization | 197 |
| <i>Kaiqiao Zheng, Jing Luo, and Yuqing Yan</i> | |
| Comparison of Physiological Responses to Stroop Word Color Test and IAPS Stimulation | 211 |
| <i>Sayedjavad Ziaratnia, Peeraya Sripiyan, Tipporn Laohakangvalvit, and Midori Sugaya</i> | |
| IoT and AI in Medicine and Healthcare | |
| Artificial Intelligence for Clinical Intensive Care in the Hospital: Opportunities and Challenges | 225 |
| <i>Kirsten Brukamp</i> | |
| Proposal of a Prototype Wireless Network Based on IoT that Allows the Monitoring of Vital Signs of Patients | 236 |
| <i>Leonel Hernandez, Aji Prasetya, Jainer Enrique Molina-Romero, Leonardo Campis, Jose Ruiz Ariza, Hugo Hernández Palma, and Emilse María Vásquez Avendaño</i> | |

| | |
|---|-----|
| <p>Mel Frequency Cepstral Coefficients and Support Vector Machines for Cough Detection</p> <p style="padding-left: 20px;"><i>Mpho Mashika and Dustin van der Haar</i></p> | 250 |
| <p>Multi-stakeholder Approach for Designing an AI Model to Predict Treatment Adherence</p> <p style="padding-left: 20px;"><i>Beatriz Merino-Barbancho, Peña Arroyo, Miguel Rujas, Ana Cipric, Nicholas Ciccone, Francisco Lupiáñez-Villanueva, Ana Roca-Umbert Würth, Frans Folkvord, María Fernanda Cabrera, María Teresa Arredondo, and Giuseppe Fico</i></p> | 260 |
| <p>Using Lean Six Sigma and Discrete-Event Simulation to Reduce Patient Waiting Time Before Sample Collection: A Clinical Lab Case Study</p> <p style="padding-left: 20px;"><i>Miguel Ortiz-Barrios, Matías García-Constantino, Zahiry Castro-Camargo, Cindy Charris-Maldonado, Sulay Escorcía-Charris, Gisell Sierra-Urbina, Estefany Molinares-Ramírez, Alina Torres-Mercado, Armando Pérez-Aguilar, and Pedro López-Meza</i></p> | 272 |
| <p>A Hybrid Fuzzy MCDM Approach to Identify the Intervention Priority Level of Covid-19 Patients in the Emergency Department: A Case Study</p> <p style="padding-left: 20px;"><i>Armando Perez-Aguilar, Miguel Ortiz-Barrios, Pablo Pancardo, and Fernando Orrante-Weber-Burque</i></p> | 284 |
| <p>Generation of Consistent Slip, Trip and Fall Kinematic Data via Instability Detection and Recovery Performance Analysis for Use in Machine Learning Algorithms for (Near) Fall Detection</p> <p style="padding-left: 20px;"><i>Moritz Schneider, Anika Weber, Mirko Kaufmann, Annette Kluge, Ulrich Hartmann, Kiros Karamanidis, and Rolf Ellegast</i></p> | 298 |
| <p>Safe Environments to Understand Medical AI - Designing a Diabetes Simulation Interface for Users of Automated Insulin Delivery</p> <p style="padding-left: 20px;"><i>Tim Schrills, Marthe Gruner, Heiko Peuscher, and Thomas Franke</i></p> | 306 |
| <p>Advanced Artificial Intelligence Methods for Medical Applications</p> <p style="padding-left: 20px;"><i>Thitirat Siriborvornratanakul</i></p> | 329 |
| <p>Automated Nystagmus Parameter Determination: Differentiating Nystagmic from Voluntary Eye-Movements</p> <p style="padding-left: 20px;"><i>Alexander Walther, Julian Striegl, Claudia Loitsch, Sebastian Pannasch, and Gerhard Weber</i></p> | 341 |

Modeling Complex Human Behavior and Phenomena


| | |
|---|-----|
| Disaster Mitigation Education Through the Use of the InaRISK Personal Application in Indonesia | 357 |
| <i>Afisa, Achmad Nurmandi, Misran, and Dimas Subekti</i> | |
| Using Agent-Based Modeling to Understand Complex Social Phenomena - A Curriculum Approach | 368 |
| <i>André Calero Valdez, Johannes Nakayama, Luisa Vervier, Hendrik Nunner, and Martina Ziefle</i> | |
| Policy-Based Reinforcement Learning for Assortative Matching in Human Behavior Modeling | 378 |
| <i>Ou Deng and Qun Jin</i> | |
| The Influence of Background Color and Font Size of Mobile Payment App Interface on Elderly User Experience | 392 |
| <i>Hongyu Du, Weilin Liu, Peicheng Wang, Xiang Sun, and Wenping Zhang</i> | |
| A Roadmap for Technological Innovation in Multimodal Communication Research | 402 |
| <i>Alina Gregori, Federica Amici, Ingmar Brilmayer, Aleksandra Ćwiek, Lennart Fritzsche, Susanne Fuchs, Alexander Henlein, Oliver Herbort, Frank Kügler, Jens Lemanski, Katja Liebal, Andy Lücking, Alexander Mehler, Kim Tien Nguyen, Wim Pouw, Pilar Prieto, Patrick Louis Rohrer, Paula G. Sánchez-Ramón, Martin Schulte-Rüther, Petra B. Schumacher, Stefan R. Schweinberger, Volker Struckmeier, Patrick C. Trettenbrein, and Celina I. von Eiff</i> | |
| News Articles on Social Media: Showing Balanced Content Adds More Credibility Than Trust Badges or User Ratings | 439 |
| <i>Patrick Halbach, Laura Burbach, Martina Ziefle, and André Calero Valdez</i> | |
| Semantic Scene Builder: Towards a Context Sensitive Text-to-3D Scene Framework | 461 |
| <i>Alexander Henlein, Attila Kett, Daniel Baumartz, Giuseppe Abrami, Alexander Mehler, Johannes Bastian, Yannic Blecher, David Budgenhagen, Roman Christof, Tim-Oliver Ewald, Tim Fauerbach, Patrick Masny, Julian Mende, Paul Schnüire, and Marc Viel</i> | |
| A Digital Human Emotion Modeling Application Using Metaverse Technology in the Post-COVID-19 Era | 480 |
| <i>Chutisant Kerdvibulvech</i> | |

| | |
|--|------------|
| Bibliometric Analysis and Systematic Literature Review on Data Visualization | 490 |
| <i>Byeongmok Kim, Yonggab Kim, and Vincent G. Duffy</i> | |
| A Modular Framework for Modelling and Verification of Activities in Ambient Intelligent Systems | 503 |
| <i>Alexandros Konios, Yasir Intiaz Khan, Matias Garcia-Constantino, and Irvin Hussein Lopez-Nava</i> | |
| An Analysis and Review of Maintenance-Related Commercial Aviation Accidents and Incidents | 531 |
| <i>Neelakshi Majumdar, Divya Bhargava, Tracy El Khoury, Karen Marais, and Vincent G. Duffy</i> | |
| Analysis of Human Factors and Resilience Competences in ASRS Data Using Natural Language Processing | 548 |
| <i>Mako Ono and Miwa Nakanishi</i> | |
| Non-immersive vs. Immersive: The Difference in Empathy, User Engagement, and User Experience When Simulating the Daily Life of Rheumatoid Arthritis Patients | 562 |
| <i>Alexicia Richardson, Cheryl D. Seals, Kimberly B. Garza, Gary Hawkins, Sathish Akula, Sean Kim, Adam Biggs, Lily McGuckin, Ravindra Joshi, and Majdi Lusta</i> | |
| Trend Analysis on Experience Evaluation of Intelligent Automobile Cockpit Based on Bibliometrics | 576 |
| <i>Lei Wu and Qinqin Sheng</i> | |
| Intelligent Human-Computer Interaction Interface: A Bibliometric Analysis of 2010–2022 | 590 |
| <i>Yi Zhang, Yaqin Cao, Yu Liu, and Xiangjun Hu</i> | |
| Author Index | 605 |

Human Factors and Ergonomics



TWINMED T-SHIRT, a Smart Wearable System for ECG and EMG Monitoring for Rehabilitation with Exoskeletons

Paolo Perego¹(✉) , Roberto Sironi¹, Emanuele Gruppioni² ,
and Giuseppe Andreoni¹ 

¹ Design Department, Politecnico Di Milano, Via Candiani 72, 20158 Milan, (MI), Italy
paolo.perego@polimi.it

² Centro Protesi Inail, Via Rabuina, 14, 40054 Vigorso, (BO), Italy

Abstract. Wearable devices have become increasingly popular in recent years and have been utilized in a range of different fields, including healthcare, fitness, and entertainment. In particular, the development of smart textiles has been a major breakthrough in the wearable technology industry. This paper discusses the design and development of a wearable system for muscular and cardio-respiratory evaluation for rehabilitation with exoskeleton.

The paper is focus on the Twinmed system which consists in an exoskeleton and a smart t-shirt that records cardiac and muscle signals through silver-based 3D textile electrodes. The t-shirt has been designed tailored onto the patient's measurements for optimal sensor placement, and each sensor is connected to a device that can monitor the two main signals: muscular and cardiac.

The system was developed with a focus on evaluating the progress of rehabilitation and proper use of crutches during exoskeleton walking. All the design features have been selected through collaboration and interaction with project stockholders: patients, therapists, and engineers. The system has been pretested in laboratory both without and with the exoskeleton and have been shown to be effective for monitoring EMG signals and provide physicians with a clearer view of the cardiovascular exertion required, while allowing patients to have quantitative feedback on their health status.

Keywords: Rehabilitation · Wearable device · Exoskeleton

1 The Twinmed System

1.1 The System

Wearable devices for rehabilitation are quickly becoming an integral part of modern health care. These devices can provide users with accurate data and feedback on their physical condition and progress, allowing medical professionals to better track and monitor their patient's progress. Wearable devices can be used to track movement, posture, and range of motion, as well as other important health metrics [1]2.

Physical rehabilitation can include helping with physical therapy, as well as helping patients recover from injuries or surgery. Additionally, wearable devices can help to provide patients with more motivation to take part in their rehabilitation, as they can see their progress and results in real time [3, 4].

Wearable devices are also becoming more personalized, with some devices being specifically designed for certain conditions [5]. For example, devices designed for physical rehabilitation can measure more specific metrics related to a patient's specific condition, allowing medical professionals to track progress more accurately.

In this paper authors report the design and test process for a new wearable system based on a smart t-shirt. The system has been designed specifically for supporting and evaluating the patient during the rehabilitation process with an exoskeleton.

This research is part of a project funded by INAIL (National institute for insurance against industrial injuries) which starts from a previous project who seen the development of a new modular exoskeleton by Rehab Technologies Lab IIT-INAIL (Genova, Italy). The project TWIN [6] consist in a novel modular lower limb exoskeleton for personal use of spinal-cord injury (SCI) subjects. The exoskeleton was designed based on features requested by users during participatory investigation which were attended by patients, engineers, designers and therapists. The TWIN exoskeleton was therefore designed to have the following characteristics (lightweight and portability, quick and autonomous wearing and setup, cost effectiveness, long battery life, comfort and safety, and especially stability during standing and walking). Figure 1 shows the TWIN exoskeleton in action.



Fig. 1: The exoskeleton Twin without the smart t-shirt

In the last years, the use of robots and exoskeletons for rehabilitation is becoming more common, but very often only the orthopedic and neurological aspects are considered, leaving out the whole cardiovascular aspect instead.

In this kind of rehabilitation, it is important to consider the potential risks to the cardiovascular system. When individuals use exoskeletons, they are often engaging in physical activity that they might not be able to perform unassisted; this can lead to an increase in heart rate, blood pressure, and cardiac output, which can put additional stress on the cardiovascular system, which in most cases comes from periods of inactivity due to post-surgery or post-disease course. Mulroy et al. [7] that patients with spinal cord injuries who used exoskeletons for walking experienced an increase in heart rate and blood pressure. The study also found that the patients had a higher cardiac output during exoskeleton-assisted walking compared to walking without the exoskeleton. These findings suggest that the use of exoskeletons for rehabilitation can put additional stress on the cardiovascular system; the authors concluded that the use of robots for rehabilitation should be carefully monitored to avoid any adverse effects on the cardiovascular system.

It is important to note that while the use of robots and exoskeletons for rehabilitation can be beneficial for patients, it can also pose risks to their cardiovascular health. Patients with pre-existing cardiovascular conditions, such as hypertension or heart disease, may be at higher risk for adverse effects. Therefore, it is important to carefully evaluate patients before using these devices and to monitor their cardiovascular health throughout the rehabilitation process. Medical professionals should also be aware of the potential risks and take appropriate precautions to ensure patient safety.

It has also been pointed out that in many cases, during the use of rehabilitation robots or exoskeletons on patients with spinal injuries there is an increase in extrasystoles that go to further highlight the danger of using these systems if not properly supervised.

2 Design the T-shirt

As described in the previous section, cardio-respiratory monitoring during rehabilitation exercise with robots and exoskeletons is of paramount importance to prevent risky events for patients. On the other hand, another critically important aspect in rehabilitation is clinical adherence to therapy, that is, in case of rehabilitation, how committed the patient is to continue with the exercises assigned to him or her by the therapist over time. The issue that most often plagues those who do home rehabilitation, or tele-rehabilitation, is dropout: on the one hand because progress is not always immediately visible, and on the other hand because the exercises that are usually offered are repetitive and boring.

The wearable system described in this paper has the main goal of heuristic patient monitoring. To optimize the type of measurements and the number of signals acquired, the system was designed by considering the users from the first stages.

By user we mean not only the end users, i.e., patients, but all stakeholders who are part of the group of people who design, configure, install, and use the system.

To do this, the so-called double diamond methodology, or rather, in this case, triple diamond [8] was tapped, which is especially applicable to hardware and software design context.

The Triple Diamond methodology is a design thinking approach that builds on the Double Diamond methodology. The key difference between the Triple and Double Diamond models is that the Triple Diamond places a greater emphasis on implementation and delivery, whereas the Double Diamond focuses more heavily on ideation and problem-solving. The Double Diamond model consists of two main stages: discover and define, with a focus on exploring the problem and generating ideas. The Triple Diamond model adds a third stage, deliver, which emphasizes the importance of implementing and delivering a solution that meets the needs of the users and the business.

The Triple Diamond model consists of three main stages: discovery, define, and deliver. Each of these stages is further broken down into specific steps [9].

The first stage, discovery, is about understanding the problem and the context in which it exists. This stage involves research, observation, and empathy to gain insights into the problem and the people affected by it. The goal is to identify the real problem to be solved and the opportunities for innovation. As described above, in this stage patients and therapist who use exoskeleton were observed in order to extract information and main problems during all the phase of the rehabilitation: preparation, execution and conclusion.

The second stage, define, is about synthesizing the information gathered in the discovery stage to define the problem statement and create a clear design brief. This stage involves analyzing the data collected in the discovery stage and identifying patterns and themes. The goal is to create a clear and actionable problem statement that will guide the ideation and prototyping phases. In order to better understand user's needs, in this second stage we involved all the stakeholder directly in the process by means of focus groups. The focus group was held at a clinical rehabilitation institute and involved physical therapists, physicians, engineers, and patients, for a total of 8 people. During the focus group, physicians stressed the importance of having available, in addition to the electrocardiographic signal, a respiratory signal that can immediately highlight possible fatigue problems.

They also emphasized the need to acquire muscle signals (through surface electromyography) for the upper body only, to highlight how well the patient is walking correctly with the exoskeleton or not, a kind of biofeedback. This last part was the most discussed during the focus group because it needed a trade-off between engineers and clinicians; while from the clinician point of view a lot of EMG signals is necessary to have an optimal analysis of all body movement, there is also a trade-off with the need to make the system portable, small, and wearable. Moreover, another technical problem is related to the type of data transmission to integrate; in fact, if the most widely used technology in wearables is Bluetooth LE, this allows up to a maximum of 7 devices connected simultaneously, thus limiting the number of wearable devices that can be used, and consequently the signals acquired.

The third stage, deliver, is about creating and implementing a solution based on the problem statement and design brief. This stage involves ideation, prototyping, testing, and iteration to create a viable solution. The goal is to create a solution that meets the needs of the users and the business requirements. This last stage, combined with the outcomes from the focus group, emphasized the importance of having the wearable

system developed on two fronts: a design related to comfort while using the exoskeleton, and a design related to monitoring.

2.1 Comfort Design

Figure 2 shows the first analysis outcome on the patient using the lower limb exoskeleton. The figure shows a first approach to the design of the wearable system where the positioning for EMG signal acquisition, positioning for ECG and breathing signal acquisition, pressure sensors for measuring discomfort at the thoracic level, and soft parts to decrease discomfort in some areas where the exoskeleton might be uncomfortable are visible.

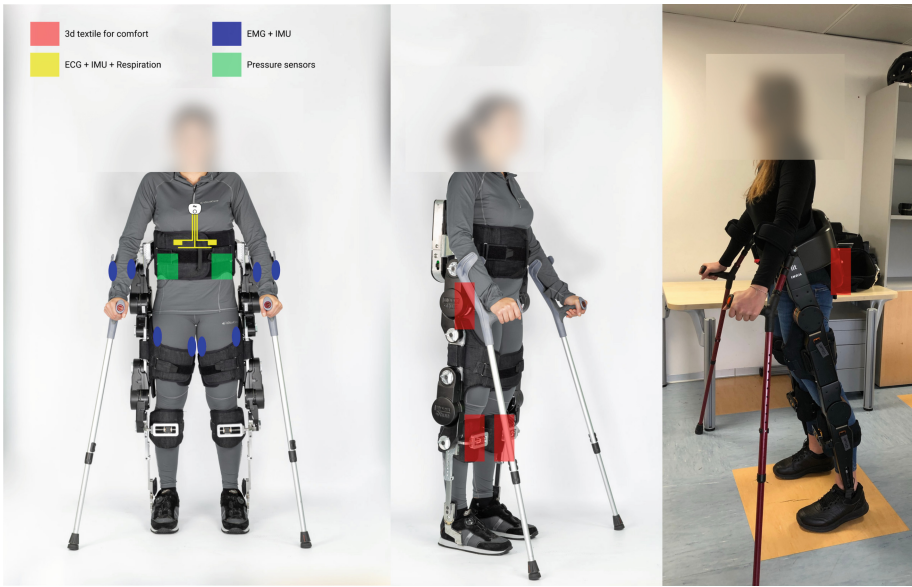


Fig. 2. First design for the wearable design. On the left the signal parts, on the right the comfort part

As visible in the figure, the red rectangle indicates the possible positions underline during the ghosting phase in which the contact of the exoskeleton can be in contact with the patient’s body and create discomfort or injuries. After a more thorough analysis with who designed the exoskeleton, thanks in part to modifications built into the braces that hold exoskeleton in place, the points where contact discomfort is possible have decreased. However, the parts below the knee and on the back remaining of possible interference.

Different solutions can be used to minimize discomfort due to the contact between exoskeleton and skin. The pressure generated by this contact may change depending on the size of the patient who wear the exoskeleton. However, having the goal of designing

a sensorised t-shirt/suit, the most suitable choice turns out to be the implementation of “special” fabric in the garment that can absorb pressure and work as a protection.

A 3D textile is a fabric that has a three-dimensional structure, usually created by using fibers or yarns of different lengths or by using a variety of weaving or knitting techniques. In garment design, 3D textiles can be used to provide additional protection or cushioning in areas that are prone to impact or wear. They can also be used to provide structural support or to create unique aesthetic effects.

Figure 3 shows an example of 3d textile; the thickness of the fabric is generated by a weave made from fabric with a high polyamide component. Although the fabric is composed mainly of plastic material, a surface finish can be given to make it comfortable. In addition, the texturing of the fabric allows air circulation, so as to avoid heavy sweating that occurs when the worn fabric is synthetic.



Fig. 3. Example of 3d textile applied as comfortable cushion for exoskeleton joint

2.2 Smart T-shirt Design

The second design phase for the smart garment consists in the development of a solution for data acquisition. During the focus group mentioned earlier, a qualitative analysis was carried out regarding what characteristics the garment should have and what signals to acquire. Starting from a design brief shown to the participants in which many more signals than were needed were included (see Fig. 2), the focus group participants opened a discussion by comparing technical and medical needs in order to define a solution that was feasible and at the same time able to monitor the patient optimally. No longer a technology driven design, but a user’s-driven design, in which users lead development, focusing resources on what is really needed for the project.

This open discussion among all stakeholders in the project also led to drastic decisions such as removing the sensors from the lower limb, as they were deemed unnecessary for performance monitoring since they are linked to residual or passive activity generated by limb movements via the exoskeleton.

During the focus group, all participants were able to actively be part of the discussion on all the features of the system, including the more technical ones, thanks to the presence of engineers, and designers trained on technology. This made it possible to draft from the first iteration the characteristics that the system should have, including the technological point of view and its feasibility.

The main features are listed below, while Fig. 4 shows the final structure of the wearable system:

1. ECG channel on the 10th rib;
2. Thoracic breath sensor (if possible, also diaphragmatic);
3. Six channel EMG:
 - a. Right and left triceps
 - b. Right and left deltoid
 - c. Right and left middle (or upper) trapezius
4. ECG sample frequency 1 kHz;
5. EMG sample frequency 1 kHz;
6. At least 4 h battery life;
7. Bluetooth connection;
8. Small size;
9. Light weight;
10. Ease of connection with the garment;
11. LED for status.

The wearable system shown in Fig. 4 consists of three devices each capable of measuring two EMG signals, and a fourth device for measuring the ECG signal and respiration. The ECG device also records, through an inertial motion unit, the patient's trunk position. The devices are connected to the T-shirt by means of four snaps buttons each. The snap buttons were preferred over a connection with spring and magnetic probes in order to be able to optimize the measurement of signals, especially EMG signals which are much more sensitive to noise than ECG ones.

Each device has a button for control and an LED that identifies status through color change and flashing. The devices can be connected to a hub through the Bluetooth connection. However, since the signals are acquired with a fairly high sampling rate, the Bluetooth connection is over-used and requires high performance hub with specific characteristics that can support this kind of transmission (e.g.. Bluetooth 5.2 with at least 247 byte MTU, 2M Physical Layer and < 15 ms priority).

The sensorized T-shirt is made of highly elastic fabric, in order to maintain a strong adhesion to the skin and optimize the acquired signals, minimizing disturbances due to movement and rubbing of the electrodes with the skin. The electrodes are made of 3D conductive fabric based on silver. It was chosen to use a 3D conductive fabric instead of a more common plain conductive fabric for two main reasons:

- being three-dimensional and having the component that generates the three-dimensionality also conductive, the characteristics of an electrode made with this fabric approach those of a classic Ag-AgCl electrode (the impedance is much lower than the plain fabric).

- the three-dimensionality creates a sponge effect, which retains water/sweat or electrode gel; this further improves the conductivity of the electrodes and therefore the quality of the signal.

The size of the electrodes is optimized based on the measurement to be taken. The two ECG electrodes (the right leg drive is removed) have a size of 20×30 mm. The electrode then narrows to a strip of thickness 10 mm, which is used to transmit the ECG signal from the actual electrode to the automatic button used for connection with the electronic device. The breath sensor is instead composed by a special fiber of TPU charged with graphene powder. The graphene adds conductivity to the fiber that, when subject to stretching or squashing, change. This change in conductivity can be used to monitor fiber elongation; if this fiber is applied to a shirt in the thoracic or diaphragmatic region, the enlargement of the rib cage or diaphragmatic breathing cause a lengthening of the fiber thus making it possible to monitor respiration.

Unlike the ECG signal, the position, shape, and dimension of EMG electrodes are important factors which can affect the signal quality and accuracy of the measurement [10].

The position of EMG electrodes is crucial for obtaining accurate and meaningful data. The electrodes must be placed over the muscle of interest, as close as possible to the motor endplate zone, where the muscle fibers are innervated by the motor neuron. Placement of the electrodes in the optimal position ensures that the recorded signal is representative of the activity of the muscle fibers. The muscle length and orientation of the fibers can also affect the recorded signal. Therefore, it is important to standardize the placement of the electrodes for each muscle group.

The electrode should be large enough to capture the electrical activity of the muscle, but not so large that it picks up signals from neighboring muscles. An electrode that is too small may not pick up enough signal, while an electrode that is too large may pick up signals from other muscles or from the skin. The shape of the electrode can also affect the signal quality, with rounded electrodes being preferred over square or rectangular ones.

Another choice to make when dealing with EMG is whether to use a unipolar or bipolar system. Bipolar EMG consist of three electrodes: two are placed on the skin over the muscle of interest. The third electrode is placed at fixed distance apart from the other two and used as reference.

Unipolar EMG electrodes consist of only two electrodes, one for the measurement and one for the reference. The recording electrodes is placed over the muscle of interest, while the reference electrode is placed on a nearby bone or tendon. This kind of configuration allows for using less electrodes, which is essential when designing a smart garment because it allows to minimize the number of electrodes and, in the case of this specific project, the number of connections between device and garments. Moreover, this type of EMG recording provides more spatial resolution than bipolar ones.

The electrodes on the t-shirt follow the unipolar configuration; the shape, size and position are based on Seniam [11] guidelines.



Fig. 4. The sensorised t-shirt. The devices are connected on the back for trapezius EMG, on the arm for deltoids and triceps, and on the front for ECG and respiration measurement.

3 System Test

To verify the correct functioning of the system, three different types of tests were implemented.

The first test was carried out to verify the feasibility of measuring EMG through textile electrodes in a unipolar configuration, structured according to the Seniam guidelines [11]. To simplify the test operations, instead of monitoring the muscles listed above, it was preferred to measure the EMG on the brachioradialis and ulnar flexor muscles. To do this, a sleeve was made inside which the textile electrodes were positioned, connected to a medical snap button with the possibility of connecting a commercial EMG device. The test protocol involved two consecutive measurements, the first with the sensorised sleeve, and the second with the classic Ag-AgCl electrodes positioned like those present in the sleeve. The subject was asked to isometrically flex and extend the wrist in order to collect the activation of the two muscles. The two signals were subsequently compared to check if the textile electrodes were able to record muscle activation, and fatigue.

The second test was carried out with the aim to verify the correct position of the electrode on the t-shirt. Figure 5 show this test and the EMG signal acquired during gait with crutches. The protocol foresaw the subject wore the sensorized shirt connected to a commercial EMG (FREEMG Wireless surface EMG by BTS Bioengineering) while walking with crutches. The healthy subject simulated a correct walk with crutches and a walk instead with incorrect support of the crutches. The two types of walking activate the muscles in different ways, giving the possibility to have feedback on the correct use of the exoskeleton.

The third test was performed with the exoskeleton. The objective of this latest test was to verify the interferences between the exoskeleton and the smart T-shirt, in order to possibly optimize the position of the electrodes on the shirt. The protocol envisaged the use of EMG devices developed ad-hoc for the project. The test was carried out in two different phases: a first phase with isometric contractions to verify the correct functioning of the system; a second phase in which all signals were acquired during the use of the exoskeletal. All the data have been than processed by means of specific algorithm in order to verify the quality of the signals.

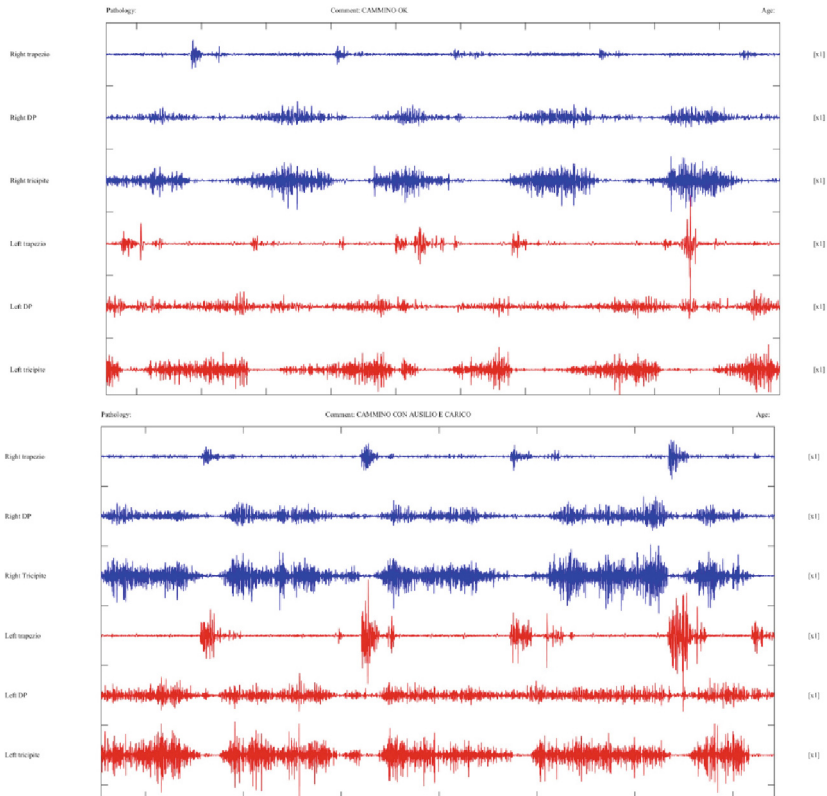


Fig. 5. EMG acquired with the sensorised T-shirt. The first chart shows the activation of the six muscles during the correct use of crouches; the second chart show the activation of the same muscle with wrong support of the crutches.

4 Conclusion

The data recorded during the first two test sessions made it possible to optimize the size and especially the production process of sensors in order to obtain clean signals comparable with the ones recorded through classic modes. The third test has allowed to check if the sensorised T-shirt developed was able to detect the signals during the use of the exoskeleton. The acquired data show an excellent signal quality when the subject uses the exoskeleton but in a static position. During the gait, on the other hand, the exoskeleton interferes with the correct functioning of the sensorised T-shirt. In particular, the signal that is more affected by noise is the cardio-respiratory one. The exoskeleton is in fact anchored to the body by means of a thoracic brace that has the edges exactly near the textile electrodes and the strain gauge. This involves many disorders on the two signals that prevent the correct measure of cardio-respiratory parameters. The modification of the brace or the repositioning of the electrodes in such a way that they are completely covered by the brace, significantly improves the quality of the signal (Fig. 6).

As for EMG signals, the quality is adequate to be able to carry out an analysis on muscles activations. Also in this case, during movements (raised and seat) the handling with crutches causes movements of the T-shirt, with the consequent insertion of signal noise. Moreover, these movements in some cases cause the complete detachment of the electrode (in particular the trapezius), completely preventing the signal measure.

In conclusion, the tests have shown how a sensorised shirt, designed for a specific goal, can be used for monitoring during rehabilitation with exoskeleton. It is mandatory to take into consideration that it is a smart garment, built with conductive textile and that does not use conductive gels to optimize the interface with the skin. It therefore follows that the use of the classic measures obviously has a better signal quality, but at the expense of the usability and quality of life of the wearer, as well as the quality of rehabilitation therapy.

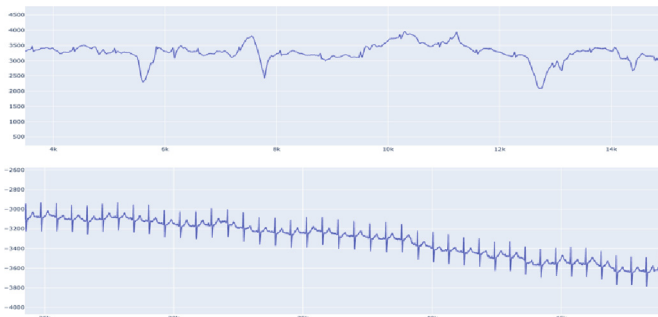


Fig. 6. ECG signals during gait with exoskeleton. The first one is visibly affected by noise generated by the rubbing of thoracic brace on the textile electrodes. The second one shows a clear ECG when electrodes are completely covered by the brace.

References

1. Rodgers, M.M., Alon, G., Pai, V.M., Conroy, R.S.: Wearable technologies for active living and rehabilitation: current research challenges and future opportunities. *J. Rehabil. Assist. Technol. Eng.* **6**, 2055668319839607 (2019)
2. Bonato, P.: Advances in wearable technology for rehabilitation. In: *Advanced Technologies in Rehabilitation*, pp. 145–159. IOS Press (2009) Kindly
3. Maceira-Elvira, P., Popa, T., Schmid, A.C., Hummel, F.C.: Wearable technology in stroke rehabilitation: towards improved diagnosis and treatment of upper-limb motor impairment. *J. Neuroeng. Rehabil.* **16**(1), 1–18 (2019)
4. Bowman, T., et al.: Wearable devices for biofeedback rehabilitation: a systematic review and meta-analysis to design application rules and estimate the effectiveness on balance and gait outcomes in neurological diseases. *Sensors* **21**(10), 3444 (2021)
5. Wang, Q., Markopoulos, P., Yu, B., Chen, W., Timmermans, A.: Interactive wearable systems for upper body rehabilitation: a systematic review. *J. Neuroeng. Rehabil.* **14**(1), 1–21 (2017)
6. Awolusi, I., Marks, E., Hallowell, M.: Wearable technology for personalized construction safety monitoring and trending: review of applicable devices. *Autom. Constr.* **85**, 96–106 (2018)

7. Laffranchi, M., et al.: User-centered design and development of the modular twin lower limb exoskeleton. *Front. Neurobot.* **15** (2021)
8. Mulroy, S.J., Thompson, L., Kemp, B., Hatchett, P., Newsam, C.J., Lupold, D.G.: Cardiac monitoring during exoskeleton-assisted walking in patients with spinal cord injury: a case series. *Arch. Phys. Med. Rehabil.* **97**(8), S216–S223 (2016)
9. Chen, M.: The Zendesk Triple Diamond (2020). <https://medium.com/zendesk-creative-blog/the-zendesk-triple-diamond-process-fd857a11c179>
10. Design Council UK. The principles of the triple diamond (2018). <https://www.designcouncil.org.uk/news-opinion/principles-triple-diamond>
11. Campanini, I., Merlo, A., Degola, P., Merletti, R., Vezzosi, G., Farina, D.: Effect of electrode location on EMG signal envelope in leg muscles during gait. *J. Electromyogr. Kinesiol.* **17**(4), 515–526 (2007)
12. Hermens, H., Freriks, B.: The state of the art on sensors and sensor placement procedures for surface electromyography: a proposal for sensor placement procedures. Enschede, The Netherlands: Roessingh Research and Development (1997)

Author Index

A

Abele, Nils Darwin I-317
Abrami, Giuseppe I-539, II-461
Adam, Stella I-162
Afisa II-357
Aguilar, Chloe I-330
Akula, Sathish II-562
Alapati, Sreejan I-3
Alkawarit, Mahmood I-162
Amici, Federica II-402
Amith, Muhammad I-330
An, Kai I-14
André, Rafael de Pinho I-24
Andreoni, Giuseppe I-35, I-205, I-566
Aoustin, Yannick I-3
Arias, Kika II-88
Arredondo, María Teresa II-260
Arroyo, Peña II-260
Auster-Gussman, Lisa II-88
Avanzini, Pietro I-205

B

Bagci, Mevlüt I-539
Balasankar, Santhosh Kumar I-429
Bassi, Marta I-444
Bastian, Johannes II-461
Baumartz, Daniel II-461
Berckmans, Daniel I-444
Bhargava, Divya II-531
Bian, Yishan II-154
Bier, Marina I-609
Biffi, Emilia I-35
Biggs, Adam II-562
Binu, Marlyn I-102
Blanchard, Nathaniel I-592
Blecher, Yannic II-461
Borges, Adriano Mendes II-3
Bosani, Enrica I-242
Braun, Christopher I-48
Brilmayer, Ingmar II-402

Brukamp, Kirsten II-225
Brutti, Richard I-578
Budgenhagen, David II-461
Burbach, Laura II-20, II-439

C

Cabrera, María Fernanda II-260
Calero Valdez, André II-20, II-368, II-439
Campis, Leonardo II-236
Campis-Freyle, Leonardo I-395, II-104
Cao, Yaqin II-590
Carissoli, Claudia I-444
Castro-Camargo, Zahiry II-272
Casu, Giulia I-194
Cavatorta, Maria Pia I-242
Celani-De Souza, Helder Jose II-104
Chablat, D. I-497
Charris-Maldonado, Cindy II-272
Chen, Jing II-65
Chen, Qi II-65
Chen, Yuerong II-154
Cheng, Hong I-642
Chevallereau, C. I-497
Christof, Roman II-461
Cibrario, Valerio I-242
Ciccone, Nicholas II-260
Cipric, Ana II-260
Cong, Ruichen II-154
Cullen-Smith, Suzanne II-123
Cunha Monteiro, Walbert II-3
Ćwiek, Aleksandra II-402

D

De Marco, Doriana I-205
de Oliveira Vargas, Vitor I-344
de Souza, Marcelo I-24
Dei, Carla I-35, I-444
Deng, Ou II-378
Despins, Laurel I-344
Delle Fave, Antonella I-444

Ding, Lin I-14
 Ding, Lv II-77
 Dong, Ziyang I-290, II-169
 Doyle, Julie II-123
 Du, Hongyu II-392
 Duan, Runlin I-70
 Duffy, Vincent G. I-58, I-70, I-87, I-102,
 II-490, II-531

E

El Khoury, Tracy II-531
 Ellegast, Rolf I-48, II-298
 Engel, Juliane I-539
 Escorcia-Charris, Sulay II-272
 Espeleta-Aris, Andrea II-104
 Ewald, Tim-Oliver II-461

F

Fabbri Destro, Maddalena I-205
 Fauerbach, Tim II-461
 Favacho Queiroz, Vinicius II-3
 Feng, Yuan I-632
 Fico, Giuseppe II-260
 Folkvord, Frans II-260
 Fonseca, Almir I-24
 Frank, Carolin I-609
 Franke, Thomas I-368, II-306
 Friemert, Daniel I-48, I-162
 Fritzsche, Lennart II-402
 Fruhling, Ann II-138
 Fuchs, Susanne II-402

G

Gaikwad, Nandini I-58
 Ganser, Rachel II-20
 García-Constantino, Matías II-272, II-503
 Garofalo, Fabio I-355
 Garza, Kimberly B. II-562
 Ge, Chang I-525
 George, Micah Wilson I-58
 Gilbert, Kristin I-383
 Graham, Sarah II-88
 Greenwood, Allen G. I-58
 Gregori, Alina II-402
 Gruner, Marthe I-368, II-306
 Gruppioni, Emanuele I-566
 Guda, V. K. I-497
 Guo, Wenbin I-632

H

Haase, Germaine I-383
 Hafner, Florian I-609
 Halbach, Patrick II-439
 Hamilton, Jane I-330
 Hanning, Nina I-609
 Harth, Volker I-48
 Hartmann, Ulrich I-48, II-298
 Hashimoto, Nagisa I-175
 Hawkins, Gary II-562
 Hebri, Aref I-120
 Henlein, Alexander I-539, II-402, II-461
 Herbot, Oliver I-510, II-402
 Hernández Palma, Hugo II-236
 Hernandez, Leonel II-236
 Hernández-Palma, Hugo I-395
 Hoffmann, Sven I-317
 Hou, Jingming I-642
 Hu, Xiangjun II-590
 Hu, Xiuying I-642
 Hu, Xiyun I-70
 Hu, Zhe II-38
 Huang, Xu I-632
 Huang, Yingjie II-77
 Hussain, Muzammil II-49

I

Islam, Md Tariqul I-87
 Iyer, Krittika J. I-102
 Izdebski, Krzysztof I-162

J

Jacobs, An II-123
 Jaiswal, Ashish I-120
 Jiang, Yue II-65
 Jiménez-Delgado, Genett I-395, II-104
 Jin, Kevin I-135
 Jin, Qun II-154, II-378
 Jonnalagadda, Soundarya II-138
 Joshi, Ravindra II-562

K

Kahl, Anke I-609
 Kasaia Sharifi, Alireza I-344
 Karamanidis, Kiros I-48, II-298
 Kaufmann, Mirko II-298
 Kaufman-Ortiz, Kevin J. I-413
 Kerdvibulvech, Chutisant II-480
 Kett, Attila II-461

Khan, Tazrin I-330
 Khan, Yasir Imtiaz II-503
 Kim, Byeongmok II-490
 Kim, Jung Hyup I-344
 Kim, Mingyeong II-185
 Kim, Sean II-562
 Kim, Yonggab II-490
 Kluge, Annette II-298
 Kluth, Karsten I-317
 Konca, Maxim I-539
 Konios, Alexandros II-104, II-503
 Krause, Lisa-Marie I-510
 Krishnaswamy, Nikhil I-592
 Kügler, Frank II-402

L

Laguardia, Luis I-24
 Lai, Kenneth I-578
 Laohakangvalvit, Tipporn II-211
 Laun, Martin I-48
 Leban, Bruno I-194
 Lee, Kevin I-135
 Lemanski, Jens II-402
 Leuthner, Nicolai I-48
 Li, Qingchen I-147
 Li, Tiantian I-413
 Li, Yi II-38
 Li, Yuxi II-154
 Liebal, Katja II-402
 Liu, Long II-65
 Liu, Qing I-303
 Liu, Weilin II-392
 Liu, Xiangyu I-290, II-77, II-169
 Liu, Xinran I-290, II-169
 Liu, Yang I-525
 Liu, Yu II-590
 Liu, Ziyi I-70
 Loitsch, Claudia II-341
 Londoño-Lara, Luz I-395
 López-Meza, Pedro II-272
 Lopez-Nava, Irvin Hussein II-503
 Lopomo, Nicola Francesco I-35, I-205
 Lu, Jiayuan II-77
 Lücking, Andy I-539, II-402
 Luebke, Andre I-87
 Lungfiel, Andy I-276
 Luo, Jing II-197
 Lupiáñez-Villanueva, Francisco II-260
 Lusta, Majdi II-562

M

Ma, Liang I-478
 Majumdar, Neelakshi II-531
 Makedon, Fillia I-120
 Maletz, Lucia I-609
 Marais, Karen II-531
 Mashika, Mpho II-250
 Masny, Patrick II-461
 Mayat, Nils I-162
 McGuckin, Lily II-562
 Meenakshi, Sindhu I-429
 Mehler, Alexander I-539, II-402, II-461
 Meixner, Gerrit I-256
 Mekata, Yuki I-175
 Mende, Julian II-461
 Merino-Barbancho, Beatriz II-260
 Miao, Chongchong I-14
 Miao, Ke II-77
 Misran, II-357
 Molinares-Ramirez, Estefany II-272
 Molina-Romero, Jainer Enrique II-236
 Montero-Bula, Carlos I-395
 Mugisha, S. I-497

N

Nakanishi, Miwa I-175, II-548
 Nakayama, Johannes II-368
 Narula, Nandini I-102
 Navarro-Jimenez, Eduardo II-104
 Negri, Luca I-444
 Nguyen, Kim Tien II-402
 Nickel, Peter I-184, I-276
 Nishimura, Shoji II-154
 Nunner, Hendrik II-368
 Nurmandi, Achmad II-357

O

Ogihara, Atsushi II-154
 Oh, Yunmin II-88
 Ono, Mako II-548
 Orrante-Weber-Burque, Fernando II-284
 Ortiz-Barrios, Miguel II-104, II-272, II-284

P

Pancardo, Pablo II-284
 Pannasch, Sebastian II-341
 Pau, Massimiliano I-194
 Perego, Paolo I-35, I-566
 Pérez-Aguilar, Armando II-272, II-284

Peuscher, Heiko II-306
 Peña Fernández, Alberto I-444
 Pietrzyk, Ulrike I-383
 Pinatti De Carvalho, Aparecido Fabiano
 I-317
 Polak, Sara II-123
 Porta, Micaela I-194
 Pouw, Wim II-402
 Prasetya, Aji II-236
 Prieto, Pilar II-402
 Puangseree, Passawit I-355
 Pustejovsky, James I-578

Q

Qiu, Jing I-642
 Quintero-Ariza, Iván I-395
 Quintino, Marc I-539

R

Ramesh Babu, Ashwin I-120
 Reisher, Elizabeth II-138
 Rhee, Danniel I-330
 Richards, Mackenzie I-135
 Richardson, Alexicia II-562
 Roca-Umbert Würth, Ana II-260
 Rohrer, Patrick Louis II-402
 Rojas-Castro, Edgar I-395
 Romero-Gómez, Jeremy I-395
 Ruiz Ariza, Jose II-236
 Rujas, Miguel II-260

S

Sá, José Carlos I-395
 Sánchez-Ramón, Paula G. II-402
 Santana-de Oliveira, Jonas II-104
 Santos, Gilberto I-395
 Sarfraz, Isra II-49
 Saukel, Kevin I-539
 Savas, Lara S. I-330
 Scalone, Emilia I-205
 Schaub, Meike I-242
 Schiefer, Christoph I-48
 Schlenz, Anna I-215
 Schmidt, Kerstin I-215
 Schmidt, Paul I-215
 Schneider, Moritz II-298
 Schnüre, Paul II-461
 Schreiber, Jakob I-539

Schrills, Tim I-368, II-306
 Schrottenbacher, Patrick I-539
 Schüler, Thomas I-162
 Schulte-Rüther, Martin II-402
 Schumacher, Petra B. II-402
 Schwarz, Mario I-256
 Schweinberger, Stefan R. II-402
 Schweitzer, Marcus I-317
 Seals, Cheryl D. II-562
 Sepanloo, Kamelia I-87
 Serique Meiguins, Bianchi II-3
 Seth, Deep I-3
 Sharma, Abhishek II-49
 Sheng, Qinqin II-576
 Shi, Bin II-77
 Shi, Liangliang I-303
 Sierra-Urbina, Gisell II-272
 Sillevs Smitt, Myriam II-123
 Siriborvornratanakul, Thitirat II-329
 Sironi, Roberto I-566
 Soares de Sousa, Thiago Augusto II-3
 Spiekermann, Christian I-539
 Sripian, Peeraya II-211
 Stevanoni, Giulia I-35
 Storm, Fabio Alexander I-444
 Storm, Fabio I-35
 Striegl, Julian II-341
 Struckmeier, Volker II-402
 Subekti, Dimas II-357
 Sugaya, Midori II-211
 Sun, Guoqiang I-14
 Sun, Xiang II-392

T

Tago, Kiichi II-154
 Tam, Christopher I-578
 Tang, Hao II-77
 Tang, Lu I-330
 Tao, Cui I-330
 Tegtmeier, Patricia I-459
 Terhoeven, Jan I-459
 Terschüren, Claudia I-48
 Torres-Mercado, Alina II-272
 Trettenbrein, Patrick C. II-402

V

Vale Pinheiro, Kelly II-3
 van der Haar, Dustin II-250

van Leeuwen, Cora [II-123](#)
VanderHoeven, Hannah [I-592](#)
Vargas, Manuela [I-242](#)
Vásquez Avendaño, Emilse María [II-236](#)
Velluvakkandy, Ronak [I-87](#)
Vervier, Luisa [II-20, II-368](#)
Vicente, Diego [I-256](#)
Viel, Marc [II-461](#)
von Eiff, Celina I. [II-402](#)
Vox, Jan P. [I-162](#)

W

Waldorf, Julia [I-609](#)
Walther, Alexander [II-341](#)
Wang, Chen [I-478](#)
Wang, Hong [I-632](#)
Wang, Peicheng [II-392](#)
Wang, Yilin [I-642](#)
Weber, Anika [I-162, II-298](#)
Weber, Gerhard [II-341](#)
Westfal, Lucas [I-24](#)
Wetzl, Christoph [I-276](#)
Wischniewski, Sascha [I-459](#)
Wolf, Karen Insa [I-162](#)
Wu, Jianlun [II-154](#)
Wu, Lei [II-576](#)
Wu, Xiang [I-290, II-169](#)
Wu, Xu [I-14](#)
Wu, Yeqi [I-290, II-169](#)

Wu, Yongxin [I-147](#)
Wulf, Volker [I-317](#)

X

Xie, Hongqin [I-642](#)
Xiong, Wei [I-478](#)
Xu, Li [I-290, II-169](#)
Xu, Peng [I-642](#)
Xu, Tianfeng [I-290, II-169](#)
Xue, Yanmin [I-303, I-525](#)

Y

Yan, Wen [I-525](#)
Yan, Yuqing [II-197](#)
Ye, Yaping [II-154](#)
Yi, Jae Sun [II-185](#)
Yokoyama, Kayo [I-24](#)
Yu, Suihuai [I-303](#)

Z

Zaki Zadeh, Mohammad [I-120](#)
Zhang, Di [II-77](#)
Zhang, Wenping [II-392](#)
Zhang, Yi [II-590](#)
Zheng, Kaiqiao [II-197](#)
Zhou, Yihui [I-525](#)
Ziaratnia, Sayyedjavad [II-211](#)
Ziefle, Martina [II-20, II-368, II-439](#)
Zlatkin-Troitschanskaia, Olga [I-539](#)