

Proceedings

**2022 IEEE Conference on Virtual Reality
and 3D User Interfaces Abstracts
and Workshops**

VRW 2022

Proceedings

2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops

12 – 16 March 2022
Virtual Event



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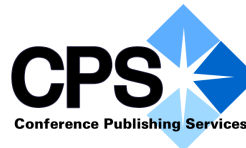
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IEEE VR 2022 Abstracts and Workshops Table of Content

IEEE VR 2022 Workshops.....	xxiii
IEEE VR 2022 Tutorials	xxx
IEEE VR 2022 Panels.....	xxxii

Workshop 1: 5th IEEE VR Internal Workshop on Animation in Virtual and Augmented Environments (ANIVAE-2022)

A Cardboard-Based Virtual Reality Study on Self-Avatar Appearance and Breathing.....	1
Dixuan Cui, Christos Mousas	
Virtual Veracity: Animated Documentaries and Mixed Realities	7
Nea Ehrlich	
Towards AR for Large-Scale Robotics.....	15
Johannes Braumann, Emanuel Gollob, Amir Bastan	
Behind the Curtains: Comparing Mozilla Hubs with Microsoft Teams in a Guided Virtual Theater Experience.....	19
Jürgen Hagler, Michael Lankes, Nils Gallist	
View-Adaptive Asymmetric Image Detail Enhancement for 360-degree Stereoscopic VR Content	23
Kin-Ming Wong	
Digital Puppetry: Utilizing Extended Reality Technologies for Animations.....	27
Milad Tousi, Katja Gallhuber, Michael Lankes	
Pericles VR: Insights into visual development and gamification of a lesser known Shakespeare play	31
Hannes Rall, Emma Harper	

Workshop 2: Open Access Tools and Libraries for VR

HeadBox: A Facial Blendshape Animation Toolkit for the Microsoft Rocketbox Library.....	39
Matias Volonte, Eyal Ofek, Ken Jakubzak, Shawn Bruner, Mar Gonzalez-Franco	
STAG: A Tool for realtime Replay and Analysis of Spatial Trajectory and Gaze Information captured in Immersive Environments	43
Aryabrata Basu	
Excite-O-Meter: an Open-Source Unity Plugin to Analyze Heart Activity and Movement Trajectories in Custom VR Environments.....	46
Luis Quintero, Panagiotis Papapetrou, John E. Muñoz, Jeroen de Mooij, Michael Gaebler	
Developing Mixed Reality Applications with Platform for Situated Intelligence	48
Sean Andrist, Dan Bohus, Ashley Feniello, Nick Saw	
Asymmetric Normalization in Social Virtual Reality Studies.....	51
Jonas Deuchler, Daniel Hepperle, Matthias Wölfel	
An Open Platform for Research about Cognitive Load in Virtual Reality	54
Olivier Augereau, Gabriel Brocheton, Pedro Paulo DO Prado Neto	
Physics-based character animation for Virtual Reality	56
Joan Llobera, Caecilia Charbonnier	
NUI-SpatialMarkers: AR Spatial Markers For the Rest of Us.....	58
Alex G Karduna	

Human Vision vs. Computer Vision: A Readability Study in a Virtual Reality Environment.....	61
Zhu Qing, Praveen Edara	
RealityFlow: Open-Source Multi-User Immersive Authorings	65
John T. Murray	
Integrating Rocketbox Avatars with the Ubiq Social VR platform.....	69
Lisa Izzouzi, Anthony Steed	
BabiaXR: Virtual Reality software data visualizations for the Web	71
David Moreno-Lumbreras, Jesus M. Gonzalez-Barahona, Andrea Villaverde	

Workshop 3: 3D Reconstruction, Digital Twinning, Simulation

Lightweight Collision Detection Algorithm in Web3D Robot Simulation Platform.....	75
Weiqiang Wang, Hantao Zhao, Jinyuan Ji	
DentalVerse: Interactive Metaverse Virtual Reality Implementation to Train Preclinical Dental Student Psychomotor Skill	81
Markus Santoso, Sadie Crawford, Erica Del Hagen, Jiaming Du, Emily Husak, Zihang Liao, Cortino Sukotjo	
Investigating Lighting Quality in Office Workstations: A Combined Approach Utilizing Virtual Reality and Physical Workstations	85
Roxana Jafarifiroozabadi, Piers MacNaughton, Alina Osnaga	
Designing VR training systems for children with attention deficit hyperactivity disorder (ADHD).....	88
Ho Yan Kwan, Lang Lin, Conor Fahy, Jethro Shell, Shiqi Pang, Yongkang Xing	
3D Reconstruction, Digital Twinning, and Virtual Reality: Architectural Heritage Applications.....	92
Marco Giorgio Bevilacqua, Andrea Giordano, Michele Russo, Roberta Spallone	
Application of LargeSpace for Investigating Pedestrians' Behaviors when Interacting with Autonomous Vehicles in Shared Spaces	97
Andri Janto, Zhangyijing Chen, Takuro Kodama, Hiroaki Yano, Makoto Itoh	
Photogrammabot: An Autonomous ROS-Based Mobile Photography Robot for Precise 3D Reconstruction and Mapping of Large Indoor Spaces for Mixed Reality.....	101
Soroosh Mortezaipoor, Christian Schönauer, Julien Rüggeberg, Hannes Kaufmann	
Challenges of experimenting with Virtual Reality	108
Krzysztof Szczurowski, Matt Smith	
Immersive Virtual Reality for Virtual and Digital Twins: A Literature Review to Identify State of the Art and Perspectives	114
Johanna Pirker, Enrica Loria, Saeed Safikhani, Andreas Künz, Sabrina Rosmann	
Developing a VR Simulator for Robotics Navigation and Human Robot Interactions employing Digital Twins	121
Silas F. R. Alves, Alvaro Uribe-Quevedo, Delun Chen, Jon Morris, Sina Radmard	
Are you Seeing what I'm Seeing?: Perceptual Issues with Digital Twins in Virtual Reality	126
Brian Adrian Flowers, Summer Rebensky	

Workshop 4: AR Enabling Superhuman Sports + Serious Games

Designing WindCage- Unpacking the Thinking and Prototyping a Propeller-Based Haptic Unit	131
Kao-Hua Liu, Tomoya Sasaki, Hiroyuki Kajihara, Atsushi Hiyama, Masahiko Inami, Chien-Hsu Chen	
Advancing tangible augmented game objects for use in a golf swing, self-service training environment: Report of Work-in-Progress with a Multidisciplinary Emphasis.....	136
Anthony Luczak, J. Adam Jones, Reuben Burch, Jonathan Barlow, Patrick Nelsen, Steven M. Grice, Michael Taquino, Martin Duclos, Caleb Morgan	

Workshop 5: Building the Foundations of the Metaverse

Reality Check of Metaverse: A First Look at Commercial Social Virtual Reality Platform.....	141
Ruizhi Cheng, Nan Wu, Songqing Chen, Bo Han	
CWCT: An Effective Vision Transformer using improved Cross-Window Self-Attention and CNN.....	149
Mengxing Li, Ying Song, Bo Wang	
Environmental, User, and Social Context-Aware Augmented Reality for Supporting Personal Development and Change.....	155
Timothy Scargill, Ying Chen, Sangjun Eom, Jessilyn Dunn, Maria Gorlatova	
Extended Reality and Internet of Things for Hyper-Connected Metaverse Environments	163
Jie Guan, Jay Irizawa, Alexis Morris	
Scaling-up AR: University Campus as a Physical-Digital Metaverse	169
Tristan Braud, Carlos Bermejo Fernandez, Pan Hui	

Workshop 6: Datasets for Developing Intelligent XR Apps

A dataset and methodology for self-efficacy feeling prediction during industry 4.0 VR activity	176
Thibaud Bounhar, Zaher Yamak, Vincent Havard, David Baudry	
Identification of Key Features for VR Applications with VREVIEW: A Topic Model Approach	183
Yang Qian, YingQiu Xiong, Yuyang Wang, Yuanchun Jiang, Yezheng Liu, Yidong Chai	
SSV360: A Dataset on Subjective Quality Assessment of 360 Videos for Standing and Seated Viewing on an HMD	189
Majed Elwardy, Hans-Jürgen Zepernick, Yan Hu	
Real Time Egocentric Object Segmentation for Mixed Reality: THU-READ Labeling and Benchmarking Results.....	195
E. Gonzalez-Sosa, G. Robledo, D. González Morín, P. Perez-Garcia, A. Villegas	
The Hitchhiker's Guide to the Metaverse	203
Pan Hui	

Workshop 7: Empathic Computing

Empathy building 'in the wild' - a reflection on avoidance of the emotional engagement	204
Magdalena Igras-Cybulska, Artur Cybulski, Damian Galuszka, Jan Smolarczyk	
Effects of Heart Rate Feedback on an Asymmetric Platform using Augmented Reality and Laptop	209
Arindam Dey, Yufei Cao, Chelsea Dobbins	
Designing and Implementing Individualized VR for Supporting Depression	217
Ilona Halim, Nilufar Baghaei, Lehan Stemmet, Mark Billingham, Richard Porter	
Conceptual Design of Emotional and Pain Expressions of a Virtual Patient in a Virtual Reality Training for Paramedics	222
Guillermo Carbonell, Jonas Schild	
Empathic Skills Training in Virtual Reality: A Scoping Review.....	227
Lynda Joy Gerry, Mark Billingham, Elizabeth Broadbent	
Exploring empathy with digital humans	233
Kate Loveys, Mark Sagar, Mark Billingham, Nastaran Saffaryazdi, Elizabeth Broadbent	

Workshop 8: Everyday Virtual Reality

Comparing Teleportation Methods for Travel in Everyday Virtual Reality.....	238
Dominic Lesaca, Henry Cheung, Tapaswini Jena, Daniel Cliburn	
Web XR User Interface Study in Designing 3D Layout Framework in Static Websites.....	243
Yongkang Xing, Jethro Shell, Conor Fahy, Congyuan Wen, Zheng Da, Ho Yan Kwan	

From attention to action: Key drivers to augment VR experience for everyday consumer applications 247
Svetlana Bialkova

Virtual Try-On: How to Enhance Consumer Experience?..... 253
Svetlana Bialkova, Chloe Barr

Workshop 9: K-12+ Embodied Learning through V and AR

School students creating a virtual reality learning resource for children..... 261
Erica Southgate, Steve W Grant, Simon Ostrowski, Andrew Paul David Norwood, Monica Williams, Dara Tafazoli

Improving Language Learning by an Interact-to-Learn Desktop VR Application: A Case Study with Peinture 267
Xiao Liu, Shuwei Zhang, Tao Xu, Yun Zhou

Exploring Factors Associated with Retention in Computer Science Using Virtual Reality 271
Vidya Gaddy, Francisco Raul Ortega

Bot Undercover: On the Use of Conversational Agents to Stimulate Teacher-Students Interaction in Remote Learning..... 277
Filippo Gabriele Praticò, Javad Alizadeh Shabkhoslati, Navid Shaghghi, Fabrizio Lamberti

TeachInVR: A virtual reality classroom for remote education..... 283
Florian Schier, Krishnan Chandran, Matthew McGinity

Towards VR Simulation-Based Training in Brain Death Determination 287
Pascal Kockwelp, Anna Junga, Dimitar Valkov, Bernhard Marschall, Markus Holling, Benjamin Risse

Collaborative Learning with Augmented Reality Tornado Simulator..... 293
Yan-Ming Chiou, Chien-Chung Shen

Visualized Cues for Enhancing Spatial Ability Training in Virtual Reality 299
Qian Chen, Lixia Deng, Tao Xu, Yun Zhou

Workshop 10: Metaverse as a promise of a bright_future

Reading Social Media Marketing Messages as Simulated Self Within a Metaverse: An Analysis of Gaze and Social Media
Engagement Behaviors within a Metaverse Platform..... 301
Yongwoog “Andy” Jeon

Workshop 11: Novel Input Devices and Interaction Techniques

IMPRESS: Improved Multi Touch Progressive Refinement Selection Strategy 304
Elaheh Samimi, Robert J. Teather

My Eyes Hurt: Effects of Jitter in 3D Gaze Tracking..... 310
Moaz Hudhud Mughrabi, Aunnoy K Mutasim, Wolfgang Stuerzlinger, Anil Ufuk Batmaz

Study of Thin Polymer pre-charge Multi point Tactile device..... 316
Junji Sone, Tatsuya Sato, Shinmyo Yanagawa, Katsumi Yamada, Liwei Lin

Workshop 12: Socially Intelligent Virtual Agents (SIVA)

Personalization of Intelligent Virtual Agents for Motion Training in Social Settings 319
Celeste Mason, Frank Steinicke

Social Facilitation and Inhibition in Augmented Reality: Performing Motor and Cognitive Tasks in the Presence
of a Virtual Agent..... 323
Fariba Mostajeran, Pia Reisewitz, Frank Steinicke

Anthropomorphism of Virtual Agents and Human Cognitive Performance in Augmented Reality 329
Fariba Mostajeran, Nadia Burke, Nazife Ertugrul, Kilian Hildebrandt, Joshua Matov, Noémie Tapie, Wilhelm Gottlieb Zittel,
Pia Reisewitz, Frank Steinicke

Local Free-View Neural 3D Head Synthesis for Virtual Group Meetings.....	333
Sebastian Rings, Frank Steinicke	
Behaviour Privacy: Non-verbal Threats in Avatar-based VR Systems.....	338
Dilshani Kumarapeli, Sungchul Jung, Robert W. Lindeman	
Advanced Emotion Analytics of Virtual Group Meetings involving Intelligent Virtual Agents	344
Nidhi Joshi, Niklas Beecken, Hawa Bah, Frank Steinicke, Juliane Degner	

Workshop 13: Sonic Interaction in Virtual Environments

Designing Sound Synthesis Interfaces for Head-mounted Augmented Reality	351
Yichen Wang, Charles Martin	
The Effect of Spatial Audio on the Virtual Representation of Personal Space	354
Lauren Buck, Mauricio Flores Vargas, Rachel McDonnell	
QiaoLe: Accessing Traditional Chinese Musical Instruments in VR.....	357
Jiali Zhang, Nick Bryan-Kinns	

Workshop 14: 3D Content Creation for Sim. Training (TrainingXR)

QoE Study of Natural Interaction in Extended Reality Environment for Immersive Training	363
Carlos Cortés, María Rubio, Pablo Perez, Beatriz Sánchez, Narciso García	
Simulating Wind Tower Construction Process for Virtual Construction Safety Training and Active Learning.....	369
Wanwan Li, Behzad Esmaeili, Lap-Fai Yu	
MARS: A Cross-Platform Mobile AR System for Remote Collaborative Instruction and Installation Support using Digital Twins	373
Slawomir K. Tadeja, Diana Janik, Przemyslaw Stachura, Maciej Tomecki, Karol Książczak, Krzysztof Walas	
A New Model for Cognitive IVT based on IoT for Critical Safety Solutions: Firefighter Usecase.....	381
Mohamed Saifeddine hadj sassi, Mina Saghafian, Federica Battisti, Marco Carli	
A Study of Real-time Information on User Behaviors during Search and Rescue (SAR) Training of Firefighters	387
Shahin Doroudian, Zekun Wu, Weichao Wang, Alexia Galati, Aidong Lu	
AR Hero: Generating Interactive Augmented Reality Guitar Tutorials.....	395
Lucas Ribeiro Skreining, Ana Stanescu, Shohei Mori, Frank Heyen, Peter Mohr, Michael Sedlmair, Dieter Schmalstieg, Denis Kalkofen	

Workshop 15: XR for Healthcare and Wellbeing

AR-Assisted Surgical Guidance System for Ventriculostomy.....	402
Sangjun Eom, Seijung Kim, Shervin Rahimpour, Maria Gorlatova	
Challenges and Opportunities for Playful Technology in Health Prevention: Using Virtual Reality to Supplement Breastfeeding Education	406
Kymeng Tang, Kathrin Gerling, Luc Geurts	
Towards Virtual Teaching Hospitals for Advanced Surgical Training.....	410
Vuthea Chheang, Danny Schott, Patrick Saalfeld, Lukas Vradelis, Tobias Huber, Florentine Huettl, Hauke Lang, Bernhard Preim, Christian Hansen	
Ragdoll Recovery: Manipulating Virtual Mannequins to Aid Action Sequence Proficiency	415
Paul Watson, Swen E. Gaudl	
Designing Extended Reality Guidance for Physical Caregiving Tasks.....	419
Nicola Dell, Deborah Estrin, Harald Haraldsson, Wendy Ju	
VR Training: The Unused Opportunity to Save Lives During a Pandemic.....	423
Maximilian Rettinger, Gerhard Rigoll, Christoph Schmaderer	

Design requirements to improve laparoscopy via XR.....	425
Ezequiel R. Zorzal, Maurício Sousa, Pedro Belchior, João Madeiras Pereira, Nuno Figueiredo, Joaquim A. Jorge	
Immersive Analytics for Ergonomics Evaluation in Virtual Reality.....	430
Simon Kloiber, Nicole Weidinger, Eva Eggeling, Reinhold Preiner, Katharina Krösl, Tobias Schreck	
The Virtual Human Breathing Coach.....	434
Sanobar Dar, Aniko Ekart, Ulysses Bernardet	
AR HMD for Remote Instruction in Healthcare.....	437
Helena M. Mentis, Ignacio Avellino, Jwawon Seo	
Anatomy Studio II: A Cross-Reality Application for Teaching Anatomy.....	441
Joaquim Jorge, Pedro Belchior, Abel Gomes, Mauricio Sousa, João Madeiras Pereira, Jean-François Uhl	
Design and evaluation of an immersive ultrasound-guided locoregional anesthesia simulator.....	445
Cassandra Simon, Lucas Herfort, Amine Chellali	
Improving X-ray Diagnostics through Eye-Tracking and XR.....	450
Catarina Moreira, Isabel Blanco Nobre, Sandra Costa Sousa, João Madeiras Pereira, Joaquim Jorge	
The Development of a Common Factors Based Virtual Reality Therapy System for Remote Psychotherapy Application.....	454
Christopher Tacca, Barbara Kerr, Elizabeth Friis	
Augmented Reality and Surgery: Human Factors, Challenges, and Future Steps.....	459
Soojeong Yoo, Ann Blandford	
From Déjà vu to Déjà vécu: Reliving Surgery in Post-Operative Debriefing.....	462
Sophie Maria, Solène Lambert, Ignacio Avellino	
 Workshop 16: XR for Industrial & Occupational Supports (XRIOS)	
Design of ARQ: An Augmented Reality System for Assembly Training Enhanced with QR-Tagging and 3D Engineering Asset Model.....	466
Slawomir K. Tadeja, Diana Janik, Przemyslaw Stachura, Maciej Tomecki, Krzysztof Walas	
Situated Visualization of IIoT Data on the Hololens 2.....	472
Matthias Husinsky, Alexander Schlager, Arian Jalaefar, Stefan Klimpfinger, Manuel Schumach	
A Research Agenda for Enterprise Augmented Reality.....	477
Christine Perey, William Z. Bernstein	
An XR-based Approach to Safe Human-Robot Collaboration.....	481
Sung Ho Choi, Kyeong-Beom Park, Dong Hyeon Roh, Jae Yeol Lee, Yalda Ghasemi, Heejin Jeong	
Indirect Robot Manipulation using Eye Gazing and Head Movement for Future of Work in Mixed Reality.....	483
Kyeong-Beom Park, Sung Ho Choi, Hongju Moon, Jae Yeol Lee, Yalda Ghasemi, Heejin Jeong	
Subjective and Objective Analyses of Collaboration and Co-Presence in a Virtual Reality Remote Environment.....	485
Allison Bayro, Yalda Ghasemi, Heejin Jeong	
Search and Rescue AR Visualization Environment (SAVE): Designing an AR Application for Use with Search and Rescue Personnel.....	488
John Luksas, Kelsey Quinn, Joseph L. Gabbard, Mariam Hasan, Janet He, Neha Surana, Moustafa Tabbarah, Nishant Kishan Teckchandani	
"Put your feet in open pit" - A WebXR Unity Application for Learning about the Technological Processes in the Open Pit Mine.....	493
Radoslaw Pomykala, Michal Patyk, Mateusz Sikora, Artur Cybulski, Julia Boniecka, Jakub Juszcak, Tadeusz Klatka, Maciej Kedzierski, Magdalena Igras-Cybulska	
Wearable Augmented Reality Interface Design for Bridge Inspection.....	497
Alan Smith, Charlie Duff, Rodrigo Sarlo, Joseph L. Gabbard	

Virtual Reality in Small and Medium-Sized Enterprises: A Systematic Literature Review.....	502
Sandra Brettschuh, Michael Holly, Maria Hulla, Patrick Herstätter, Johanna Pirker	
BuildAR: A Proof-of-Concept Prototype of Intelligent Augmented Reality in Construction.....	508
Doug A. Bowman, Joseph L. Gabbard, Nazila Roofigari-Esfahan, Keerthana Adapa, Daniel Auerbach, Kathryn Britt, Cory I. Ilo	
Group-based VR Training to Improve Hazard Recognition, Evaluation, and Control for Highway Construction Workers	513
Nazila Roofigari-Esfahan, Curt Porterfield, Todd Ogle, Tanner Upthegrove, Myounghoon Jeon, Sang Won Lee	
Nurse Perceptions of the Usability of Augmented Reality to Support Clinical Decision Making: Results of a Pilot Study	517
Nicholas E. Anton, Guoyang Zhou, Tera Hornbeck, Denny Yu	
The Effects of Augmented Reality Head-Up Display Graphics on Driver Situation Awareness and Takeover Performance in Driving Automation Systems.....	521
Richard L. Greatbatch, Hyungil Kim, Zachary Doerzaph	
An Overview of the 1st International Workshop on eXtended Reality for Industrial and Occupational Supports (XRIOS).....	523
Heejin Jeong, Isaac Cho, Kangsoo Kim, Hyungil Kim, Myounghoon Jeon	
 Workshop 17: Health and Safety in VR and AR	
Human Factors Related to Cybersickness Tolerance in Virtual Environment	528
Adrian K. T. Ng, Cheryl H. Y. Leung, Leith K. Y. Chan, Henry Y. K. Lau	
Getting the Most out of Virtual Reality: Evaluating Short Breaks to Reduce Cybersickness and Cognitive Aftereffects	533
Ankrét Szpak, Adan Richards, Stefan Carlo Michalski, Tobias Loetscher	
 Posters	
Effects of Clutching Mechanism on Remote Object Manipulation Tasks	538
Zihan Gao, Huiqiang Wang, Anqi Ge, Hongwu Lv, Guangsheng Feng	
A Testbed for Exploring Multi-Level Precueing in Augmented Reality	540
Jen-Shuo Liu, Barbara Tversky, Steven Feiner	
Resolution Tradeoff in Gameplay Experience, Performance, and Simulator Sickness in Virtual Reality Games.....	542
Jialin Wang, Rongkai Shi, Zehui Xiao, Xueying Qin, Hai-Ning Liang	
Taming Cyclops: Mixed Reality Head-Mounted Displays as Laser Safety Goggles for Advanced Optics Laboratories.....	544
Ke Li, Aradhana Choudhuri, Susanne Schmidt, Reinhard Bacher, Ingmar Hartl, Wim Leemans, Frank Steinicke	
VCoach: Enabling Personalized Boxing Training in Virtual Reality	546
Hao Chen, Yujia Wang, Wei Liang	
Control with Vergence Eye Movement in Augmented Reality See-Through Vision.....	548
Zhimin Wang, Yuxin Zhao, Feng Lu	
Semi-Analytical Surface Tension Model for Free Surface Flows	550
Nurshat Menglik, Hebin Yao, Yi Zheng, Jian Shi, Ying Qiao, Xiaowei He	
Deformable Torso Anatomy Education with Three-Dimensional Autostereoscopic Visualization and Free-Hand Interaction.....	552
Nan Zhang, Hongkai Wang, Tianqi Huang, Xinran Zhang, Hongen Liao	
Absence Agents: Mitigating Interruptions in Extended Reality Remote Collaboration.....	554
Huyen Nguyen, Thomas Bruhn, Christian Sandor, Patrick Bourdot	
Group WiM: A Group Navigation Technique for Collaborative Virtual Reality Environments.....	556
Vuthea Chheang, Florian Heinrich, Fabian Joeres, Patrick Saalfeld, Bernhard Preim, Christian Hansen	
CV-Mora Based Lip Sync Facial Animations for Japanese Speech.....	558
Ryoto Kato, Yusuke Kikuchi, Vibol Yem, Yasushi Ikei	

Impact of Parameter Disentanglement on Collaborative Alignment.....	560
Tianyu Song, Alejandro Martin-Gomez, Qiaochu Wang, Arian Mehrfard, Javad Fotouhi, Daniel Roth, Ulrich Eck, Nassir Navab	
Gaze Capture based Considerate Behaviour Control of Virtual Guiding Agent.....	562
Pinjung Chen, Hironori Mitake, Shoichi Hasegawa	
Perceptions of Colour Pickers and Companions in Virtual Reality Art-Making.....	564
Marylyn Alex, Burkhard C. Wünsche, Danielle Lottridge	
Light VR Client for Point Cloud Navigation with 360° Images	566
Clément Dluzniewski, Jérémie Le Garrec, Claude Andriot, Frédéric Noël	
Vibrating tilt platform enhancing immersive experience in VR	568
Grzegorz Zwoliński, Dorota Kamińska, Anna Laska-Lesniewicz, Łukasz Adamek	
Augmenting VR Ski Training using Time Distortion.....	570
Takashi Matsumoto, Erwin Wu, Hideki Koike	
FusedAR: Adaptive Environment Lighting Reconstruction for Visually Coherent Mobile AR Rendering.....	572
Yiqin Zhao, Tian Guo	
Enabling Virtual Reality Interactions in Confined Spaces by Re-Associating Finger Motions.....	574
Wen-Jie Tseng, Samuel Huron, Eric Lecolinet, Jan Gugenheimer	
Understanding Shoulder Surfer Behavior Using Virtual Reality	576
Yasmeen Abdrabou, Radiah Rivu, Tarek Ammar, Jonathan Liebers, Alia Saad, Carina Liebers, Uwe Gruenefeld, Pascal Knierim, Mohamed Khamis, Ville Mäkelä, Stefan Schneegass, Florian Alt	
Designing a Physiological Loop for the Adaptation of Virtual Human Characters in a Social VR Scenario.....	578
Francesco Chiossi, Robin Welsch, Steeven Villa, Lewis L. Chuang, Sven Mayer	
Initial Evaluation of Immersive Gesture Exploration with GestureExplorer	580
Ang Li, Jiazhou Liu, Max Cordeil, Barrett Ens	
Multi Touch Smartphone Based Progressive Refinement VR Selection.....	582
Elaheh Samimi, Robert J. Teather	
Investigating Display Position of a Head-Fixed Augmented Reality Notification for Dual-task	584
Hyunjin Lee, Woontack Woo	
Priority-Dependent Display of Notifications in the Peripheral Field of View of Smart Glasses.....	586
Anja K. Faulhaber, Moritz Hoppe, Ludger Schmidt	
Studying the User Adaptability to Hyperbolic Spaces and Delay Time Scenarios	588
Ana R. Rebelo, Rui Nóbrega, Fernando Birra	
Augmented Reality Fitts' Law Input Comparison Between Touchpad, Pointing Gesture, and Raycast.....	590
Domenick M. Mifsud, Adam S. Williams, Francisco Ortega, Robert J. Teather	
Predictive Power of Pupil Dynamics in a Team Based Virtual Reality Task.....	592
Yinuo Qin, Weijia Zhang, Richard Lee, Xiaoxiao Sun, Paul Sajda	
High-speed Gaze-oriented Projection by Cross-ratio-based Eye Tracking with Dual Infrared Imaging.....	594
Ayumi Matsumoto, Tomohiro Sueishi, Masatoshi Ishikawa	
VR Wayfinding Training for People with Visual Impairment using VR Treadmill and VR Tracker	596
Sangsun Han, Pilhyoun Yoon, Miyeon Ha, Kibum Kim	
"What a Mess!": Traces of Use to Increase Asynchronous Social Presence in Shared Virtual Environments	598
Linda Hirsch, Anna Haller, Andreas Butz, Ceenu George	
Ebublio: Edge Assisted Multi-user 360-Degree Video Streaming.....	600
Yili Jin, Junhua Liu, Fangxin Wang	

Beyond Flicker, Beyond Blur: View-coherent Metameric Light Fields for Foveated Display	602
Prithvi Kohli, David R. Walton, Rafael Kuffner dos Anjos, Anthony Steed, Tobias Ritschel	
HoloInset: 3D Biomedical Image Data Exploration through Augmented Hologram Insets	604
JunYoung Choi, Haejin Jeong, Won-Ki Jeong	
3Dify: Extruding Common 2D Charts with Timeseries Data.....	606
Richard Brath, Martin Matusiak	
Design and Evaluation of an Augmented Reality App for Learning Spatial Transformations and their Mathematical Representations	608
Zohreh Shaghaghian, Heather Burte, Dezhen Song, Wei Yan	
KARLI: Kid-friendly Augmented Reality for Primary School Health Education.....	610
Mariella Seel, Michael Andorfer, Mario Heller, Andreas Jakl	
VR Education on Historic Lunar Roving Missions	612
Huadong Zhang, Lizhou Cao, Gel Howell, Chao Peng	
The Immediate and Retained Effects of One-time Virtual Reality Exposure on Intercultural Sensitivity	614
Richard Chen Li, Angel Lo Lo Kon, Justin Juk Man So, Horace Ho Shing Ip	
Comparing Principally Imagination and Interaction Versions of a Play Anywhere Mobile AR Location-Based Story	616
Gideon Raeburn, Laurissa Tokarchuk	
Retargeting Destinations of Passive Props for Enhancing Haptic Feedback in Virtual Reality.....	618
Xuanhui Yang, Yixiao Kang, Xubo Yang	
Design of Mentally and Physically Demanding Tasks as Distractors of Rotation Gains	620
Daniel Neves Coelho, Frank Steinicke, Eike Langbehn	
Minimaps for Impossible Spaces: Improving Spatial Cognition in Self-Overlapping Virtual Rooms.....	622
Rafael Epplée, Eike Langbehn	
Moving Visual-Inertial Odometry into Cross-platform Web for Markerless Augmented Reality	624
Yakun Huang, Zhijie Tan, Xiuquan Qiao, Jie Zhao, Fenghua Tian	
Augmenting Sculpture with Immersive Sonification	626
Yichen Wang, Henry Gardner, Charles Martin, Matt Adcock	
Automatic Virtual Portals Placement for Efficient VR Navigation.....	628
Lili Wang, Yi Liu, Xiaolong Liu, Jian Wu	
STARE: Semantic Augmented Reality Decision Support in Smart Environments.....	630
Mengya Zheng, Xingyu Pan, Nestor Velasco Bermeo, Rosemary J. Thomas, David Coyle, Gregory M.P. O'Hare, Abraham G. Campbell	
Material Reflectance Property Estimation of Complex Objects Using an Attention Network.....	632
Bin Cheng, Junli Zhao, Fuqing Duan	
Emotional Support Companions in Virtual Reality	634
Linda Graf, Sophie Abramowski, Melina Baßfeld, Kirsten Gerschermann, Marius Gießhammer, Leslie Scholemann, Maic Masuch	
Heuristic Short-term Path Prediction for Spontaneous Human Locomotion in Virtual Open Spaces.....	636
Christian Hirt, Marco Ketznel, Philip Graf, Christian Holz, Andreas Kunz	
3D Scene Reconstruction from RGB Images Using Dynamic Graph Convolution for Augmented Reality	638
Tzu-Hsuan Weng, Robin Fischer, Li-Chen Fu	
Towards Eye-Perspective Rendering for Optical See-Through Head-Mounted Displays.....	640
Gerlinde Emsenhuber, Michael Domhardt, Tobias Langlotz, Denis Kalkofen, Markus Tatzgern	
Feasibility of Training Elite Athletes for Improving their Mental Imagery Ability Using Virtual Reality	642
Yuanjie Wu, Stephan Lukosch, Heide Lukosch, Robert W. Lindeman, Ryan Douglas McKee, Shunsuke Fukuden, Cameron Ross, Dave Collins	

Designing a Mixed Reality System for Exploring Genetic Mutation Data of Cancer Patients	644
Syeda Aniqah Imtiaz, Alexander Bakogorge, Nour Abu Hantash, Caleb Barynin, Roozbeh Manshaei, Ali Mazalek	
A Pinch-based Text Entry Method for Head-mounted Displays	646
Haiyan Jiang, Dongdong Weng, Xiaonuo DongYe, Yue Liu	
Analysis of Emotional Tendency and Syntactic Properties of VR Game Reviews	648
Yang Gao, Anqi Chen, Susan Chi, Guangtao Zhang, Aimin Hao	
Emotional Avatars: Effect of Uncanniness in Identifying Emotions using Avatar Expressions	650
Dilshani Kumarapeli, Sungchul Jung, Robert W. Lindeman	
Role of Dynamic Affordance and Cognitive Load in the Design of Extended Reality based Simulation Environments for Surgical Contexts	652
Avinash Gupta, J. Cecil, Miguel Pirela-Cruz	
MienCap: Performance-Based Facial Animation with Live Mood Dynamics	654
Ye Pan, Ruisi Zhang, Jingying Wang, Nengfu Chen, Yilin Qiu, Yu Ding, Kenny Mitchell	
Preliminary Analysis of Effective Assistance Timing for Iterative Visual Search Tasks Using Gaze-Based Visual Cognition Estimation.....	656
Syunsuke Yoshida, Makoto Sei, Akira Utsumi, Hirotake Yamazoe	
Prototyping a Virtual Agent for Pre-school English Teaching.....	658
Eduardo Benitez Sandoval, Diego Vázquez Rojas, Clarissa A. Parada Cereceres, Alvaro Anzueto Rios, Amit Barde, Mark Billingham	
Towards Conducting Effective Locomotion Through Hardware Transformation in Head-Mounted-Device - A Review Study	660
Y Pawankumar Gururaj, Raghav Mittal, Sai Anirudh Karre, Y. Raghu Reddy, Syed Azeemuddin	
A Tangible Augmented Reality Programming Learning Environment for textual languages.....	662
Dmitry Resnyansky, Mark Billingham, Gun Lee	
Improved Offset Handling in Hand-centered Object Manipulation Extending Ray-casting	664
Emil Edström, Tim Cardell, Karljohan Lundin Palmerius	
If I Share with you my Perspective, Would you Share your Data with me?	666
Tianyu Song, Ulrich Eck, Nassir Navab	
Head in the Clouds - Floating Locomotion in Virtual Reality.....	668
Priya Ganapathi, Felix J. Thiel, David Swapp, Anthony Steed	
OmniSyn: Synthesizing 360 Videos with Wide-baseline Panoramas	670
David Li, Yinda Zhang, Christian Häne, Danhang Tang, Amitabh Varshney, Ruofei Du	
Proximity in VR: The Importance of Character Attractiveness and Participant Gender.....	672
Katja Zibrek, Benjamin Niay, Anne-Hélène Olivier, Ludovic Hoyet, Julien Pettré, Rachel McDonnell	
A Comparison of Input Devices for Precise Interaction Tasks in VR-based Surgical Planning and Training.....	674
Mareen Allgaier, Vuthea Chheang, Patrick Saalfeld, Vikram Apilla, Tobias Huber, Florentine Huettl, Belal Neyazi, I. Erol Sandalcioglu, Christian Hansen, Bernhard Preim, Sylvia Saalfeld	
AiRType: An Air-Tapping Keyboard for Augmented Reality Environments	676
Necip Fazıl Yıldıran, Ülkü Meteriz-Yıldıran, David Mohaisen	
Interacting with a Torque-Controlled Virtual Human in Virtual Reality for Ergonomics Studies	678
Jacques Zhong, Vincent Weistroffer, Pauline Maurice, Claude Andriot, Francis Colas	
Head-Worn Markerless Augmented Reality Inside A Moving Vehicle.....	680
Zhiwei Zhu, Mikhail Sizintsev, Glenn Murray, Han-Pang Chiu, Ali Chaudhry, Supun Samarasekera, Rakesh Kumar	
Cloud-Based Cross-Platform Collaborative AR in Flutter.....	682
Lars Carius, Christian Eichhorn, David A. Plecher, Gudrun Klinker	

Using External Video to Attack Behavior-Based Security Mechanisms in Virtual Reality (VR)	684
Robert Miller, Natasha Kholgade Banerjee, Sean Banerjee	
How Late is Too Late? Effects of Network Latency on Audio-Visual Perception During AR Remote Musical Collaboration	686
Torin Hopkins, Suibi Che-Chuan Weng, Rishi Vanukuru, Emma A Wenzel, Amy Banic, Ellen Yi-Luen Do	
Toward Using Multi-Modal Machine Learning for User Behavior Prediction in Simulated Smart Home for Extended Reality	688
Powen Yao, Yu Hou, Yuan He, Da Cheng, Huanpu Hu, Michael Zyda	
VR-based Context Priming to Increase Student Engagement and Academic Performance	690
Dan Hawes, Ali Arya	
A Live-Coded Add-On System for Video Conferencing in Virtual Reality	692
Septian Razi, Henry Gardner, Andrew Sorensen, Matt Adcock	
From 2D to 3D: Facilitating Single-Finger Mid-Air Typing on Virtual Keyboards with Probabilistic Touch Modeling	694
Xin Yi, Chen Liang, Haozhan Chen, Jiuxu Song, Chun Yu, Yuanchun Shi	
Seamless-Walk: Novel Natural Virtual Reality Locomotion Method with a High-Resolution Tactile Sensor	696
Yunho Choi, Hyeonchang Jeon, Sungha Lee, Isaac Han, Yiyue Luo, Seungjun Kim, Wojciech Matusik, KyungJoong Kim	
Understanding the Capabilities of the HoloLens 1 and 2 in a Mixed Reality Environment for Direct Volume Rendering with a Ray-casting Algorithm	698
Hoijoon Jung, Younhyun Jung, Jinman Kim	
Splitting Large Convolutional Neural Network Layers to Run Real-Time Applications on Mixed-Reality Hardware: Extended Abstract	700
Anthony Beug, Howard J. Hamilton	
The Virtual-Augmented Reality Simulator: Evaluating OST-HMD AR calibration algorithms in VR	702
Danilo Gasques, Weichen Liu, Nadir Weibel	
Mixed Reality Support for Bridge Inspectors	704
Urs Riedlinger, Florian Klein, Marcos Hill, Christian Lambracht, Sonja Nieborowski, Ralph Holst, Sascha Bahlau, Leif Oppermann	
Study of communication modalities for teaching distance information	706
Francesco Fastelli, Cassandre Simon, Aylene Ricca, Amine Chellali	
Relationship Between the Sensory Processing Patterns and the Detection Threshold of Curvature Gain	708
Keigo Matsumoto, Takuji Narumi	
Predicting Blendshapes of Virtual Humans for Low-Delay Remote Rendering using LSTM.....	710
Haruhisa Kato, Tatsuya Kobayashi, Sei Naito	
Using 3D Reconstruction to create Pervasive Augmented Reality Experiences: A comparison.....	712
Miguel Neves, Bernardo Marques, Tiago Madeira, Paulo Dias, Beatriz Sousa Santos	
Does Remote Expert Representation really matters: A comparison of Video and AR-based Guidance	714
Bernardo Marques, Samuel Silva, Paulo Dias, Beatriz Sousa Santos	
Whac-A-Mole: Exploring Virtual Reality (VR) for Upper-Limb Post-Stroke Physical Rehabilitation Based on Participatory Design and Serious Games	716
Helder Paraense, Bernardo Marques, Paula Amorim, Paulo Dias, Beatriz Sousa Santos	
Digital Twins of Wave Energy Generation Based on Artificial Intelligence.....	718
Yuqi Liu, Xiaocheng Liu, Jinkang Guo, Ranran Lou, Zhihan Lv	
Distinguishing Visual Fatigue, Mental Workload and Acute Stress in Immersive Virtual Reality with Physiological Data: Pre-test Results	720
Alexis D. Souchet, Weifei Xie, Domitile Lourdeaux	
AIR-range: Arranging Optical Systems to Present Mid-AIR Images with Continuous Luminance on and Above a Tabletop	722
Tomoyo Kikuchi, Yuchi Yahagi, Shogo Fukushima, Saki Sakaguchi, Takeshi Naemura	

Towards Scalable and Real-time Markerless Motion Capture	724
Georgios Albanis, Anargyros Chatzitofis, Spyridon Thermos, Nikolaos Zioulis, Kostas Kolomvatsos	
A Mixed Reality Guidance System for Blind and Visually Impaired People.....	726
Hannah Schieber, Constantin Kleinbeck, Charlotte Pradel, Luisa Theelke, Daniel Roth	
Holding Hands for Short-Term Group Navigation in Social Virtual Reality.....	728
Tim Weissker, Pauline Bimberg, Ankith Kodanda, Bernd Froehlich	
Third-Person Perspective Avatar Embodiment in Augmented Reality: Examining the Proteus Effect on Physical Performance.....	730
Riku Otono, Naoya Isoyama, Hideaki Uchiyama, Kiyoshi Kiyokawa	
Stay Safe! Safety Precautions for Walking on a Conventional Treadmill in VR.....	732
Sandra Birnstiel, Sebastian Oberdörfer, Marc Erich Latoschik	
Exploring How, for Whom and in Which Contexts Extended Reality Training ‘Works’ in Upskilling Healthcare Workers: A Realist Review.....	734
Norina Gasteiger, Sabine N van der Veer, Paul Wilson, Dawn Dowding	
ARTFM: Augmented Reality Visualization of Tool Functionality Manuals in Operating Rooms	736
Constantin Kleinbeck, Hannah Schieber, Sebastian Andress, Christian Krautz, Daniel Roth	
Comparing Controller with the Hand Gestures Pinch and Grab for Picking Up and Placing Virtual Objects	738
Alexander Schäfer, Gerd Reis, Didier Stricker	
Omnidirectional Neural Radiance Field for Immersive Experience	740
Qiaoge Li, Itsuki Ueda, Chun Xie, Hidehiko Shishido, Itaru Kitahara	
Social Presence in VR Empathy Game for Children: Empathic Interaction with the Virtual Characters.....	742
Ekaterina Muravevskaia, Christina Gardner-McCune	
Who do you look like? - Gaze-based authentication for workers in VR	744
Karina LaRubbio, Jeremiah Wright, Brendan David-John, Andreas Enqvist, Eakta Jain	
Depth Reduction in Light-Field Head-Mounted Displays by Generating Intermediate Images as Virtual Images	746
Yasutaka Maeda, Daiichi Koide, Hisayuki Sasaki, Kensuke Hisatomi	
Supervised Machine Learning Hand Gesture Classification in VR for Immersive Training.....	748
Ozkan Bahceci, Anasol Pena-Rios, Gavin Buckingham, Anthony Conway	
Perceptually-Based Optimization for Radiometric Projector Compensation.....	750
Ryo Akiyama, Taiki Fukiage, Shin'ya Nishida	
Effects of Mirrors on User Behavior in Social Virtual Reality Environments.....	752
Takayuki Kameoka, Seitaro Kaneko	
Implementation of an Authoring Tool for Wheelchair Simulation with Visual and Vestibular Feedback.....	754
Takumi Okawara, Kousuke Motooka, Kazuki Okugawa, Akihiro Miyata	
Robust Tangible Projection Mapping with Multi-View Contour-Based Object Tracking.....	756
Yuta Halvorson, Takumi Saito, Naoki Hashimoto	
High-Quality Surface-Based 3D Reconstruction Using 2.5D Maps	758
Lingxiao Song, Xiao Yu, Huijun Di, Weiran Wang	
MeasVR: Measurement Tools for Unity VR Applications	760
Jolly Chen, Robert G. Belleman	
Design of a VR Action Observation Tool for Rhythmic Coordination Training.....	762
James Pinkl, Michael Cohen	
Automatic 3D Avatar Generation from a Single RGB Frontal Image.....	764
Alejandro Beacco, Jaime Gallego, Mel Slater	

MR-RIEW: An MR Toolkit for Designing Remote Immersive Experiment Workflows.....	766
Riccardo Bovo, Daniele Giunchi, Anthony Steed, Thomas Heinis	
Using Direct Volume Rendering for Augmented Reality in Resource-constrained Platforms.....	768
Berk Cetinsaya, Carsten Neumann, Dirk Reiners	
Emotional Empathy and Facial Mimicry of Avatar Faces	770
Angela Saquinaula, Adriel Juarez, Joe Geigel, Reynold Bailey, Cecilia O. Alm	
A Time Reversal Symmetry Based Real-time Optical Motion Capture Missing Marker Recovery Method.....	772
Dongdong Weng, Yihan Wang, Dong Li	
Interpersonal Distance to a Speaking Avatar: Loudness Matters Irrespective of Contents.....	774
Kota Takahashi, Yasuyuki Inoue, Michiteru Kitazaki	
Let Every Seat Be Perfect! A Case Study on Combining BIM and VR for Room Planning.....	776
Wai Tong, Haotian Li, Huan Wei, Liwenhan Xie, Yanna Lin, Huamin Qu	
A Skin Pressure-type Grasping Device to Reproduce Impulse Force for Virtual Ball Games.....	778
Kazuma Yoshimura, Naoya Isoyama, Hideaki Uchiyama, Nobuchika Sakata, Kiyoshi Kiyokawa, Yoshihiro Kuroda	
Virtual Reality-Based Distraction on Pain and Performance during and after Moderate-Vigorous Intensity Cycling.....	780
Carly L. A. Wender, Phillip D. Tomporowski, Sun Joo (Grace) Ahn, Patrick J. O'Connor	
Virtual Touch Modulates Perception of Pleasant Touch.....	782
Gakumar Haraguchi, Michiteru Kitazaki	
Evaluating 3D Visual Fatigue Induced by VR Headset Using EEG and Self-attention CNN	784
Haochen Hu, Yue Liu, Kang Yue	
An Examination on Reduction of Displayed Character Shake while Walking in Place with AR Glasses.....	786
Hiromu Koide, Kei Kanari, Mie Sato	
Virtual Human Coherence and Plausibility – Towards a Validated Scale.....	788
David Mal, Erik Wolf, Nina Döllinger, Mario Botsch, Carolin Wienrich, Marc Erich Latoschik	
Democratic Video Pass-Through for Commercial Virtual Reality Devices.....	790
Diego González Morín, Francisco Pereira, Ester Gonzalez, Pablo Perez, Alvaro Villegas	
Perception of Symmetry of Actual and Modulated Self-Avatar Gait Movements During Treadmill Walking	792
Iris Willaert, Rachid Aissaoui, Sylvie Nadeau, Cyril Duclos, David R. Labbe	
Bringing Real Body as Self-Avatar into Mixed Reality: A Gamified Volcano Experience.....	794
Diego González Morín, Ester Gonzalez-Sosa, Pablo Perez-Garcia, Alvaro Villegas	
A Replication Study to Measure the Perceived Three-Dimensional Location of Virtual Objects in Optical See Through Augmented Reality.....	796
Farzana Alam Khan, Mohammed Safayet Arefin, Nate Phillips, J. Edward Swan II	
Moving Soon? Rearranging Furniture using Mixed Reality	798
Shihao Song, Yujia Wang, Wei Liang, Xiangyuan Li	
Add-on Occlusion: An External Module for Optical See-through Augmented Reality Displays to Support Mutual Occlusion	800
Yan Zhang, Kiyoshi Kiyokawa, Naoya Isoyama, Hideaki Uchiyama, Xubo Yang	
Knowing the Partner's Objective Increases Embodiment towards a Limb Controlled by the Partner.....	802
Harin Manujaya Hapuarachchi, Michiteru Kitazaki	
Assist Home Training Table Tennis Skill Acquisition via Immersive Learning and Web Technologies.....	804
Jian-Jia Weng, Yu-Hsin Wang, Calvin Ku, Dong-Xian Wu, Yi-Min Lau, Wan-Lun Tsai, Tse-Yu Pan, Min-Chun Hu, Hung-Kuo Chu, Te-Cheng Wu	
On the Effectiveness of Conveying BIM Metadata in VR Design Reviews for Healthcare Architecture	806
Emma Buchanan, Giuseppe Loporcaro, Stephan Lukosch	

Towards a Virtual Reality Math Game for Learning In Schools - A User Study.....	808
Meike Belter, Heide Lukosch	
Motion Correction of Interactive CG Avatars Using Machine Learning.....	810
Ko Suzuki, Hiroshi Mori, Fubito Toyama	
Adding Difference Flow between Virtual and Actual Motion to Reduce Sensory Mismatch and VR Sickness while Moving.....	812
Kwan Yun, Gerard J. Kim	
Who will Trust my Digital Twin? Maybe a Clerk in a Brick and Mortar Fashion Shop	814
Lorenzo Stacchio, Michele Perlino, Ulderico Vagnoni, Federica Sasso, Claudia Scorolli, Gustavo Marfia	
Event Synthesis for Light Field Videos using Recurrent Neural Networks.....	816
Zhicheng Lu, Xiaoming Chen, Yuk Ying Chung, Sen Liu	
Towards Controlling Whole Body Avatars with Partial Body-Tracking and Environmental Information.....	818
Koji Yamada, Hiroshi Mori, Fubito Toyama	
Measuring Virtual Object Location with X-Ray Vision at Action Space Distances	820
Nate Phillips, Farzana Alam Khan, Mohammed Safayet Arefin, Cindy L. Bethel, J. Edward Swan II	
Preliminary evaluation of an IVR user experience design model using eye-tracking attention measurements	822
Elena Dzardanova, Vlasios Kasapakis	
Touch the History in Virtuality: Combine Passive Haptic with 360° videos in history learning	824
Yanxiang Zhang, Yingna Wang, Qingqin Liu	
The Sloped Shoes: Influence Human Perception of the Virtual Slope	826
Yanxiang Zhang, Jialing Wu, Qingqin Liu	
Geometric Calibration with Multi-Viewpoints for Multi-Projector Systems on Arbitrary Shapes Using Homography and Pixel Maps	828
Atsuya Ueno, Toshiyuki Amano, Chisato Yamauchi	
Redirected Walking in 360° Video: Effect of Environment Size on Detection Thresholds for Translation and Rotation Gains.....	830
Yanxiang Zhang, Qingqin Liu, Yingna Wang,	
Movement Augmentation in Virtual Reality: Impact on Sense of Agency Measured by Subjective Responses and Electroencephalography.....	832
Liu Wang, Mengjie Huang, Chengxuan Qin, Yiqi Wang, Rui Yang	
Bouncing Seat: An Immersive Virtual Locomotion Interface with LSTM Based Body Gesture Estimation	834
Yoshikazu Onuki, Itsuo Kumazawa	
Hype Live: Biometric-based Sensory Feedback for Improving the Sense of Unity in VR Live Performance.....	836
Masashi Abe, Takuto Akiyoshi, Isidro Butaslac III, Zhou Hangyu, Taishi Sawabe	
Sense of Agency on Handheld AR for Virtual Object Translation.....	838
Wenxin Sun, Mengjie Huang, Chenxin Wu, Rui Yang	
A Location-Triggered Augmented Reality Walking Tour Using Snap Spectacles 2021.....	840
Aadil Mehdi Sanchawala, Mara Dimofte, Steven K. Feiner	
User-Defined Interaction Using Everyday Objects for Augmented Reality First Person Action Games.....	842
Mac Greenslade, Adrian Clark, Stephan Lukosch	
Proposing the RecursiVerse Overlay Application for the MetaVerse.....	844
Lorenzo Donatiello, Gustavo Marfia	
AmbientTransfer: Presence Enhancement by Converting Video Ambient to Users' Somatosensory Feedback	846
Xunshi Li, Xiaoming Chen, Yuk Ying Chung, Qiang Qu	

Comparing Physiological and Emotional Effects of Happy and Sad Virtual Environments Experienced in Video and Virtual Reality	848
Yuankun Zhu, Arindam Dey	
Toward Understanding the Effects of Visual and Tactile Stimuli to Reduce the Sensation of Movement with XR Mobility Platform.....	850
Taishi Sawabe, Masayuki Kanbara, Yuichiro Fujimoto, Hirokazu Kato	
Augmented Reality In-Field Observation Creation and Visualization in Underperforming Areas	852
Mengya Zheng, Nestor Velasco Bermeo, Abraham G. Campbell	
Jamming in MR: Towards Real-Time Music Collaboration in Mixed Reality	854
Ruben Schlagowski, Kunal Gupta, Silvan Mertes, Mark Billinghurst, Susanne Metzner, Elisabeth André	
Creating 3D Personal Avatars with High Quality Facial Expressions for Telecommunication and Telepresence	856
Michal Joachimczak, Juan Liu, Hiroshi Ando	
Video2Force: Experiencing Object Motion in Video with Dynamic Force Feedback based on Bio-Inspired Sensing and Processing.....	858
Guangxin Zhao, Zhaobo Wang, Xiaoming Chen, Zhicheng Lu, Yuk Ying Chung, Haisheng LI	
Effects of the Level of Detail on the Recognition of City Landmarks in Virtual Environments	860
Achref Doula, Philipp Kaufmann, Alejandro Sanchez Guinea, Max Mühlhäuser	
Facial Emotion Recognition Analysis Using Deep Learning through RGB-D Imagery of VR Participants through Partially Occluded Facial Types	862
Ian Mills, Frances cleary	
Immersive Visualization of Sneeze Simulation Data on Mobile Devices.....	864
Liangding Li, Douglas Hector Fontes, Carsten Neumann, Michael Kinzel, Dirk Reiners, Carolina Cruz-Neira	
Irish Sign Language in a Virtual Reality Environment.....	866
Ryan McCloskey	
A validation study to trigger nicotine craving in virtual reality	868
Chun-Jou Yu, Aitor Rovira, Xueni Pan, Daniel Freeman	
X-Ray Device Positioning with Augmented Reality Visual Feedback.....	870
Kartikay Tehlan, Alexander Winkler, Daniel Roth, Nassir Navab	
Towards Retargetable Animations for Industrial Augmented Reality	872
Reza Mirzaiee, Teodor Vernica, Kurt Scheuringer, William Z. Bernstein	
Synesthesia AR: Creating Sound-to-Color Synesthesia in Augmented Reality.....	874
Shashaank N, Steven Feiner	
HoloCMDS: Investigating Around Field of View Glanceable Commands Selection in AR-HMDs	876
Rajkumar Darbar, Arnaud Prouzeau, Martin Hachet	
Jitsi360: Using 360 Images for Live Tours.....	878
Alaeddin Nassani, Huidong Bai, Mark Billinghurst	
Apparent Shape Manipulation by Light-Field Projection onto a Retroreflective Surface.....	880
Jion Kanaya, Toshiyuki Amano	
Enabling Augmented Reality Incorporate with Audio on Indoor Navigation for People with Low Vision	882
Zihao Chi, Zhaofeng Niu, Taishi Sawabe	
Studying the Effect of Physical Realism on Time Perception in a HAZMAT VR Simulation.....	884
Kadir Lofca, Jason Haskins, Jason Jerald, Regis Kopper	

Virtual Reality Point Cloud Annotation.....	886
Anton Franzluebbbers, Changying Li, Andrew Paterson, Kyle Johnsen	
Flick Typing: Toward A New XR Text Input System Based on 3D Gestures and Machine Learning.....	888
Tian Yang, Powen Yao, Mike Zyda	
Feasibility of mapping engagement ratios to levels of task complexity within VR environments	890
Yobbahim J. Vite, Yaoping Hu	
Learning Environments in AR Comparing Tablet and Head-mounted Augmented Reality Devices at Room and Table Scale	892
Paul Craig, Peter Willemsen, Edward Downs, Alex Lover, William Barber	
The Digital Twins of Thor's Hammer Based on Motion Sensing	894
Zengxu Bian, Yuqi Liu, Jinkang Guo, Zhihan Lv	
Rereading the Narrative Paradox for Virtual Reality Theatre.....	896
Xiaotian Jiang, Xueni Pan, Jonathan Freeman	
Investigation of the potential use of Virtual Reality for Agoraphobia Exposure therapy.....	898
Sinead Barnett, Ian Mills, Frances Cleary	
 3DUI Contest	
Spatial Exploration with a WiM for Capturing 3D Dioramic Snapshots.....	900
Kevin Yu, Ulrich Eck, Nassir Navab	
ArtScape: Gamified Virtual Reality Art Exploration.....	902
Agapi Chrysanthakopoulou, Konstantinos Kalatzis, George Michalakis, Isidoros Michalellis, Kostantinos Moustakas	
The Rubber Slider Metaphor: Visualisation of Temporal and Geolocated Data	904
Antonin Cheymol, Gwendal Fouché, Lysa Gramoli, Yutaro Hirao, Emilie Hummel, Maé Mavromatis, Yann Moullec, Ferran Argelaguet, Florian Nouviale	
Band Overdrive: A Multi-Instrument Virtual Reality Music Rhythm Game.....	906
Junjie Wang, Shuqi Liao, Hao Wang, Christos Mousas	
Heart-In-Hand, a swapping point of view for immersive navigation in medical cardiology.....	908
Carlos J. Latorre-Rojas, Alexander Rozo-Torres, Laura Cortes-Rico, Wilson J. Sarmiento	
Artana: Art and knowledge about Anamorphosis	910
Shannon Dubreuil, Valentin Grillet, Nicolas Laurent, Jennifer Ling, Eloise Minder, Tristan Saliou, Alice Villafranca, Jean-Rémy Chardonnet	
Virtual Reality on a SWIM: Scalable World in Miniature	912
Jarod Pivovar, Jasmine DeGuzman, Evan Suma Rosenberg	
ColorBound: Comparing Menu Dynamics in Virtual Reality	914
Maxwell Bustamante, Mike Livingston, James Hilley, Hanniee Tran, Erik Lovejoy, John T. Murray	
SPE Selection Technique: A Projection-based Approach for Precise Object Interaction in Immersive Virtual Environments	916
Riccardo Ferri, Alberto Cannavò, F. Gabriele Praticò, Fabrizio Lamberti	
Experience Orchestra: Manipulating Musical Instruments in VR.....	918
Kristine Choi, Garrett Crumb, Richard Li, Raahul Natarrajan, Patrick Tong, Ole Molvig, Bobby Bodenheimer	
Clean the Ocean: An Immersive VR Experience Proposing New Modifications to Go-Go and WiM Techniques	920
Lee Lisle, Feiyu Lu, Shakiba Davari, Ibrahim Asadullah Tahmid, Alexander Giovannelli, Cory Ilo, Leonardo Pavanatto, Lei Zhang, Luke Schlueter, Doug A. Bowman	

Doctoral Consortium

[DC] Robust Redirected Walking in the Wild..... Niall L. Williams	922
[DC] Gamified VR for Socially Isolated Adolescents with Significant Illness..... U. B. Hansi Udupola	924
[DC] Dynamic facial expressions on virtual humans to facilitate virtual reality (VR) mental health therapy..... Shu Wei	926
[DC] Mixed Reality Interaction for Mobile Knowledge Work..... Verena Biener	928
[DC] Leveraging AR Cues towards New Navigation Assistant Paradigm..... Yu Zhao	930
[DC] XR for Improving Cardiac Catheter Ablation Procedure..... Manisha U. K. D. N.	932
[DC] Designing and Optimizing Daily-wear Photophobic Smart Sunglasses..... Xiaodan Hu	934
[DC] Immersive Analytics for Understanding Ecosystem Services Tradeoffs..... Benjamin T. Powley	936
[DC] Context-Aware Inference and Adaptation in Augmented Reality..... Shakiba Davari	938
[DC] Improving Multi-User Interaction for Mixed Reality Telecollaboration..... Faisal Zaman	940
[DC] A Mobile Intervention to Promote Social Skills in Children with Autism Spectrum Disorder Using AR Face Masks..... Hiroshika Premarathne	942
[DC] Balancing Realities by Smoothing Cross-Reality Interactions..... Matt Gottsacker	944
[DC] The impact of the Informational load of Presence Illusions on Users Attention and Memory..... Daniel A. Muñoz	946
[DC] Designing Immersive Tools for Supporting Cognition in Remote Scientific Collaboration..... Monsurat Olaosebikan	948
[DC] Annotation in Asynchronous Collaborative Immersive Analytic Environments using Augmented Reality..... Zahra Borhani	950
[DC] Effects of Asymmetric Locomotion Methods on Collaborative Navigation and Wayfinding in Shared Virtual Environments..... Soumyajit Chakraborty	952
[DC] Improving presence of virtual humans through paralinguistics..... Andrew Maxim	954
[DC] Using Multimodal Input in Augmented Virtual Teleportation..... Prasanth Sasikumar	956
A Tangible Augmented Reality Programming Learning Environment (TARPLE) for Active, Guided Learning..... Dmitry Resnyansky	958
[DC] Exploration of Context and Physiological Cues for Personalized Emotion-Adaptive Virtual Reality..... Kunal Gupta	960

Research Demos

Distant Hand Interaction Framework in Augmented Reality	962
Jesus Ugarte, Nahal Norouzi, Austin Erickson, Gerd Bruder, Greg Welch	
Mid-air Haptic Texture Exploration in VR	964
Orestis Georgiou, Jonatan Martinez, Abdenaceur Abdouni, Adam Harwood	
We Are Oulu: Exploring Situated Empathy through a Communal Virtual Reality Experience	966
Mohammad Sina Kiarostami, Aku Visuri, Simo Hosio	
Asymmetric interfaces with stylus and gesture for VR sketching	968
Qianyuan Zou, Huidong Bai, Lei Gao, Allan Fowler, Mark Billinghurst	
Pixel Processor Arrays For Low Latency Gaze Estimation	970
Laurie Bose, Jianing Chen, Stephen J. Carey, Piotr Dudek	
Aroaro - A Tool for Distributed Immersive Mixed Reality Visualization	972
Fernando Beltran, David White, Jing Geng	
3DCoLAR: Exploring 3D Color Selection and Surface Painting for Head Worn Augmented Reality using Hand Gestures.....	974
Louise M. Lawrence, Gun Lee, Mark Billinghurst, Damien Rompapas	
B-Handy: An Augmented Reality System for Biomechanical Measurement	976
James Campbell, Alvaro Cassinelli, Daniel Saakes, Damien Rompapas	
ORUN - A Virtual reality serious-game for kinematics learning	978
Jhasmani Tito, Tania Basso, Regina Moraes	
Demonstrating Immersive Gesture Exploration with GestureExplorer	980
Ang Li, Jiazhou Liu, Max Cordeil, Barrett Ens	
NUX IVE - a research tool for comparing voice user interface and graphical user interface in VR	982
Karolina Buchta, Piotr Wójcik, Mateusz Pelc, Agnieszka Górowska, Duarte Mota, Kostiantyn Boichenko, Konrad Nakonieczny, Krzysztof Wrona, Marta Szymczyk, Tymoteusz Czuchnowski, Justyna Janicka, Damian Galuszka, Radoslaw Sterna	
Feeding the fish: Interaction design to support listening to accounts of marginalization	984
Dylan Paré, John Craig, Scout Windsor	
Intelligence Visualization for Wave Energy Power Generation.....	986
Xiaocheng Liu, Yuqi Liu, Jinkang Guo, Ranran Lou, Zhihan Lv	
Liquid Digital Twins Based on Magnetic Fluid Toys.....	988
Yuqi Liu, Zengxu Bian, Xiaocheng Liu, Zhihan Lv	

Application of LargeSpace for Investigating Pedestrians' Behaviors when Interacting with Autonomous Vehicles in Shared Spaces

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ABSTRACT

Our research focuses on the interaction between pedestrians and AVs in shared spaces. We developed an experimental virtual reality (VR) facility named “LargeSpace” to investigate pedestrian behavior when interacting with an AV in a shared space. Trajectory analysis, distance to collision point, and deflection angle have been introduced to evaluate pedestrian behavior. The results help us design future experiments and enhance the user experience provided by LargeSpace.

Keywords: Human-machine interaction, safety, shared space, pedestrian, automated vehicles, LargeSpace.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 INTRODUCTION

The use of automated vehicles (AVs) in urban areas has recently become a popular topic in traffic safety, especially regarding their interactions with pedestrians. Studies on the interaction between pedestrians and AVs are expected to provide result in an AV's system design that is suitable with pedestrians' behavior. [1, 2, 3]. However, developing an experimental setup to study pedestrian behavior when interacting with AVs is challenging for researchers and designers.

Application of virtual reality (VR) technologies is a promising approach for simulating possible difficult situations that could occur in real traffic. For example, a previous study demonstrated that using VR and omnidirectional treadmill was effective in investigating the interaction between a pedestrian and an AV on urban roads [1].

From the viewpoint of pedestrian-AV interaction research, a study in the environment of shared space is challenging because the separation between pedestrians and vehicles is generally omitted; hence, the behaviors tend to be unpredictable [4]. Research on the

interaction of pedestrians with AVs in urban shared spaces using VR remains scarce. Thus, we aim to develop a VR simulation environment in which a real human pedestrian can walk around and interact with virtual AVs.

This study explains the development of an experimental setup for the interaction between a pedestrian and an AV using a large virtual reality facility. We introduce an experiment using this system as well.

2 DEVELOPMENT OF THE EXPERIMENTAL SETUP

We designed the experimental setup considering the conditions of shared spaces, AV behaviors, and pedestrian walking behaviors.

2.1 Shared Space

In many cases, shared spaces have been developed in the central area of a city. According to the definition of a shared space, streets are designed to improve pedestrian movement and comfort by reducing the dominance of motor vehicles [5]. There is no curb or level difference segregating pedestrians and vehicles. All road users, namely, cars, bicycles, or pedestrians, must have equal rights. These practices are used to empower pedestrian activities in urban areas.

Speed limits vary in different cities and countries. For instance, in New South Wales the speed limit is 10 km/h [6]; in Auckland, it is 20 km/h; in the UK, it is under 32 km/h [6].

Based on the above discussion, we chose one of the main streets around the Tsukuba Center as the experimental area. Several speed limits for AVs were tested in our experiment.

2.2 Autonomous Vehicle

An autonomous vehicle or self-driving car is a driverless vehicle that can travel between destinations using sensors and artificial intelligence to analyze road and traffic conditions. According to the Society of Automotive Engineers (SAE), there are six levels of automated driving from 0 to 5: manual driving to fully automated [7].

In our system, the AV in question is an SAE level 4 vehicle with no driver. The transportation network is a low-speed commuter system. Therefore, “eye-contact” between a pedestrian and an AV is not assumed in our experiment.

2.3 Pedestrian Walking Behaviors

We characterize the walking behavior of pedestrians based on two criteria: the choice of the next step and selection of the speed [8]. The choice of the next step assumes that pedestrians are walking by following given trajectories, and they can select from many

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alternatives to reach their destination. The choice of speed can be observed in the model of pedestrian crossing, wherein the relationship between speed, flow, and density is the main element of the model.

Pedestrian behavior theory suggests that analyzing a single pedestrian at a given location and given point in time is more convenient for the observer [8]. In addition, the analysis may integrate the influence of age and gender.

Our experimental setup needs to be able to measure the behavior as described above.



Figure 1: LargeSpace.

2.4 LargeSpace

We developed an experimental setup with a facility named “LargeSpace” [9]. “LargeSpace” is the largest encapsulated space with immersive display in the world; continuously projected images on an immersive screen offer us sufficient room to simulate complex traffic situations in a shared space. It is similar with the CAVE system [10]. LargeSpace consists of 12 projectors, ten computers, and 20 motion capture cameras. The motion capture system provides not only the position but also the speed and vision angle of the participants. Furthermore, cluster computers synchronize users’ perspectives in the virtual world, which allows us to monitor the motion of participants during the experiments.

The experimental environment mimics the shared space around the Tsukuba City bus station, as shown in Fig. 1.

2.5 Participants

Since sidewalks and crossings do not exist in shared spaces, therefore elderly pedestrians are a significant concern in the development of traffic safety [11]. The population of people aged 65 and over in Japan will increase to 40% by 2050, and they remain active in society [12]. Thus, we focused on the interaction of elderly pedestrians with AVs.

Consequently, we conducted a study on elderly pedestrian behavior interacting with AVs in an urban shared space using VR.

The participants in this experiment were 10 males and 9 females, with an average age of 72.1 years, $SD=3.5$, range 66 – 77 years.

2.6 Experimental Design

We designed the experiment using two walk-behavior approaches. The pedestrian trajectory describes the behavior on the crosswalks and when walking straight.

Three scenarios were used in this experiment. The first scenario is the pedestrian crosswalk following points A, B, C, and D with an AV approaching from behind, as shown in Fig. 2. In the second scenario, pedestrians see the AV approaching while crossing, following points D, C, B, and A. Finally, in scenario three, pedestrians walk straight from point E to point F while the AV follows from behind.

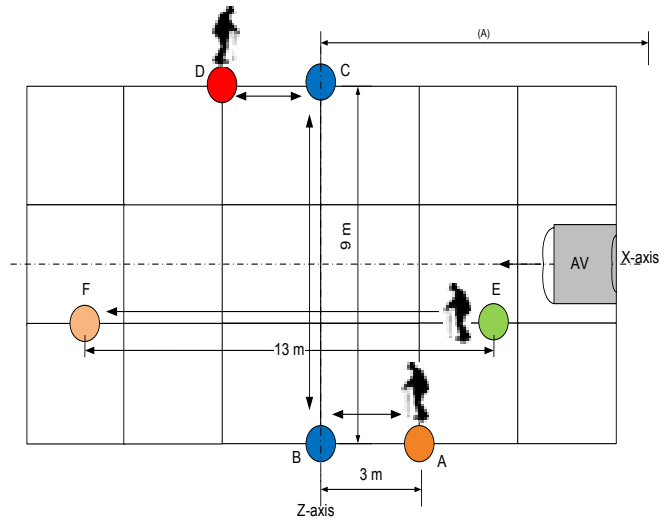


Figure 2: The three scenarios.

The AV approaches 50 m (A) from the center point and moves along the x-axis from right to left. The speed would vary between 20, 25, and 30 km/h, following the allowable speed in the shared space. The AV would not stop to let pedestrians cross because we want to investigate the acceptable speed perceived by pedestrians as safe when interacting with AVs. In addition, we will explore pedestrians’ need for a human-machine interaction (HMI) interface. Therefore, the AV does not communicate its presence.

2.7 Procedure

The participants learned the procedure before the experiment. We explained how to interact with AVs in a shared space and presented the facility. Participants rehearsed each scenario. The experiment was initiated if the participant agreed.

First, we measured the normal time (Nt) using a stopwatch as the travel time for each scenario without AV intervention.

Second, participants participated in 27 sets of scenarios; each consisting of scenarios 1, 2, and 3 sequentially. The AV speeds were 20, 25, and 30 m/h randomly for each set. We calculated the number of sets by multiplying the possible speed variations of the three scenarios. The scenarios were sequential from scenario one to three; therefore, the set number would be $1*3*1*3*1*3 = 27$ sets. The pair of scenario (S_i) and speed (V_j) was denoted as S_iV_j , $i=1, 2, 3$ and $j= 20, 25, 30$. For example, the variety of sets for one participant would be set1: $S1V30-S2V30-S3V30$, set2: $S1V25-S2V30-S3V20$, ..., set27: $S1V20-S2V30-S3V25$. The combination of sets was different for each participant. After finishing all sets, the participants were asked to fill out a questionnaire to measure their perception of safety and investigate the interface demand.

The experimental setup recorded the coordinates of the AV and participants (x, y, z-axis) and simulation time (s) for each scenario. In addition, we recorded all activities with video.

3 DATA ANALYSES

We confirmed that all the parameters were successfully obtained and calculated from the simulator, namely, traveling time (T_t), waiting time (wt), distance to collision point (d), and deflection angle (a). We constructed the pedestrian trajectory from the measured coordinates (x,z). In addition, we counted the number of waiting instances and the number of avoidances (from collision points) during the experiment.

3.1 Traveling Time (Tt)

The traveling time is measured when pedestrians walk from the start to the finish point (s). Fig. 3 illustrates the calculation of Tt. We identified the x-coordinate at the start and finish points to determine start time (t1) and finish time (t2). For example, the beginning (-3, t1) and the finish (3, t2). Thus, $Tt = t2 - t1 - wt$. Tt omitted wt for comparison to Nt. We did not subtract Tt with wt for scenario three since pedestrians were not waiting for AVs to pass.

We obtained Tt as shown in Fig. 4. On average, the females walked faster than the males. Overall, Tt for males ranged between 7.8 - 25.5 s and females 2.9 - 25.4 s. Most participants claimed they did not hesitate to crosswalk in front of AV (79%) and walk side by side with AV (63%).



Figure 3: Traveling time trajectory.

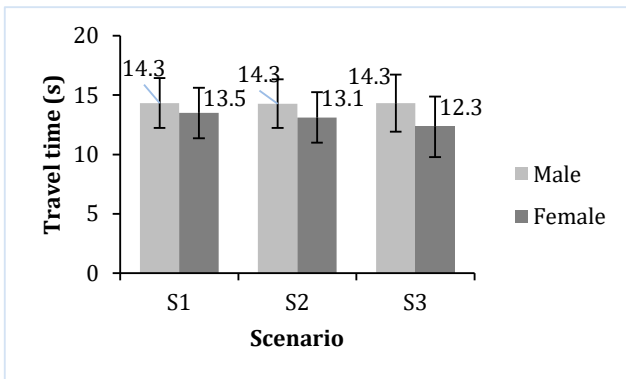


Figure 4: Average travelling time.

3.2 Waiting Time (wt)

Waiting time is measured when a pedestrian lets an AV to pass first (s). Then, we determined the pedestrian checking point to obtain the beginning time to wait (tp). Next, we chose the AV point after passing the collision point (CP) to obtain the AV passing time (tc). Thus $wt = tc - tp$. Fig. 5 presents the calculation steps.

The average waiting time for male and female pedestrians ranges from 0 - 10 s for scenario 1 and 0 - 7 s for scenario 2. A comparison of the average waiting numbers between scenarios 1 and 2 for each speed and gender are shown in Fig. 6 and 7. The result showed a natural waiting behavior in which the increasing speed of a vehicle would increase the number of waiting.

3.3 Distance to Collision Point (d)

The collision point distance and pedestrian path (d, meter) reflect how pedestrians avoid AVs by adopting a sloping trajectory, as depicted in Fig. 8.

The average avoidance distance for the male was 0.2 m, SD=0.07, range = 0.1 - 0.4 m. For the female, it was 0.2 m, SD=0.13, range = 0.1 - 0.7 m. However, the survey showed participants might

avoid the collision point because of their behavior to crosswalk. Fifty-two percent of participants might crosswalk diagonally

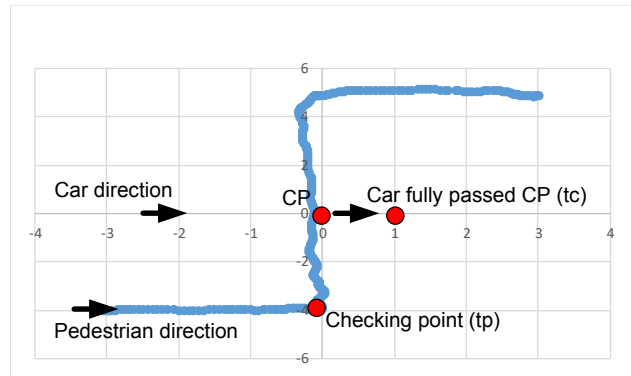


Figure 5: Waiting time.

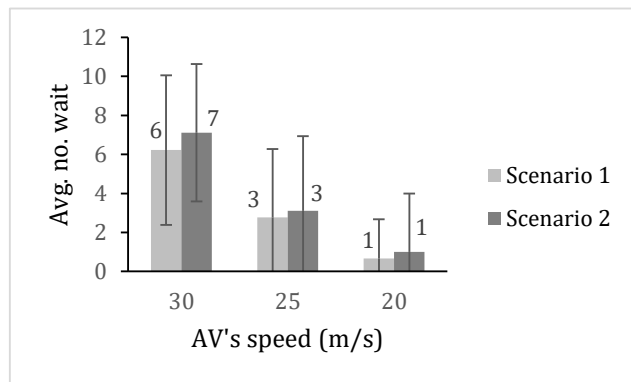


Figure 6: Male pedestrians' average number of waiting.

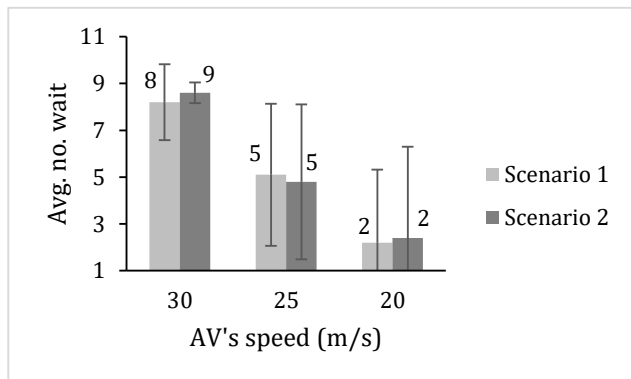


Figure 7: Female pedestrians' average number of waiting.

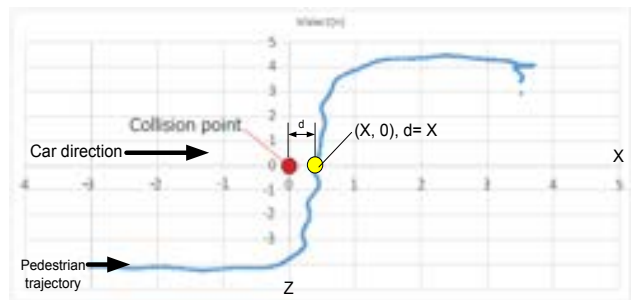


Figure 8: Distance to collision point.

3.4 Deflection Angle (a)

The angle between the straight line (start-finish in scenario 3) and pedestrian trajectory at the MP (meeting point) (degree) are shown in Fig.9. The MP is determined when the AV and pedestrian have the same position in the x-coordinate. Therefore, this angle reflects pedestrians trying to assume a greater distance from the determined path compared to the original distance because the AV passed close to them. For example, in Fig.9, $a = 15.8$ degrees.

After AV passed the meeting point, the male participants deviated on average 11.0 degrees, SD = 3.5, range = 6.4 - 19.0. The female participants deviated on average 11.9 degrees, SD = 4.5, range = 4.7 - 27.0. They disagreed with always behaving walking straightly. Also, most participants (79%) felt safe walking beside AV. So the deflection might not be because of interacting with AV.

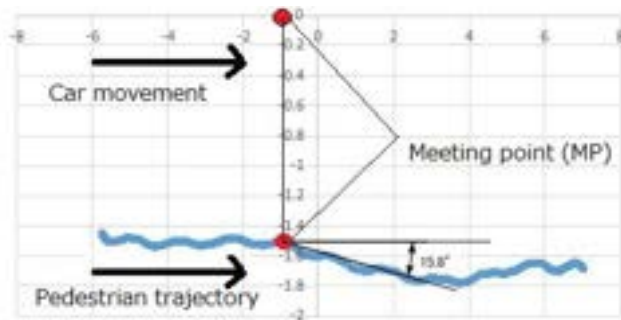


Figure 9: Deflection angle.

4 CONCLUDING REMARKS

We collected all related data experimentally. After obtaining the parameters, we used them to test the acceptance of pedestrians, especially the elderly, interacting with AVs in a shared space. However, the acceptance model has not been established yet. We are aware that there remain certain shortcomings in the experimental procedures, such as the number of participants, which was not representative of the elderly population in Japan. In addition, we were not able to further develop the behavior of the AV. for example, lane changes were not possible owing to the limitations of the simulator program used. Furthermore, the poor connectivity between the virtual glasses and simulator caused some data loss. However, we obtained valuable ideas from this experiment to develop existing facilities to support this research further.

In addition, we found that 79% of participants needed communication from AV. The interface of human-machine interactions would be a signal lamp (1), sound "beep-beep" (6), human voice (7), and music (1).

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI (Grant Number 19H00806).

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