

Possi(A)bilities: Augmented Reality Experiences of Possible Motor Abilities Enabled by a Video-Projected Virtual Hand

Radu-Daniel Vatavu

MintViz Lab, MANSiD Research Center
Ștefan cel Mare University of Suceava
Suceava 720229, Romania
radu.vatavu@usm.ro

Abstract

We introduce “Possi(A)bilities,” an Augmented Reality concept and system that presents users sitting at a table with animated visualizations of a virtual hand projected on the tabletop next to the user’s own hand. As a combination of possibilities and abilities, possi(a)bilities focus on the motor abilities of the human hand in the synchrony between the physical and the virtual, and constitute into a medium for examining and reflecting on the nature of diverse abilities that become possible when transcending the physical world and the individual’s agency. Ultimately, possi(a)bilities question assumptions, norms, and accepted definitions of motor ability and skill in the context of hybrid, physical-virtual worlds.

Keywords

Augmented Reality, Mixed Reality, video projection, motor abilities, hand function, virtual hands, Extended Reality.

Introduction

The human hand is a multifunctional instrument used to identify objects, manipulate and interact with the world, and extract information from the world via tactile sensing, active haptics, prehension, and skilled movements across a continuum of sensorimotor activities [8]. Fundamental to understanding human performance, the concepts of motor ability [3] and motor skill [12] are key for applications in motor planning and control, for characterizing individual differences in psychology [1], but also for designing interactive computer systems that adapt to and match users’ abilities [22] or repurpose the surface of the hand for input and output [6].

Either grounded in an application-oriented perspective [4, 6, 22] or taking the form of artistic expression [5, 10, 10], the diversity of the motor abilities of the human hand represents the basis for rich interactive experiences with the world. In this work, we use Augmented Reality (AR) to explore new possibilities for expressive hand movements at the intersection of the physical and the virtual. We make two contributions: (1) a technical system designed to sense, record, and visualize hand movements on a tabletop by using computer vision and AR (Figure 1), and (2) a conceptual exploration of possibilities for the motor abilities of the human hand, *i.e.*, “possi(a)bilities,” in the synchrony between the physical and the virtual world, on which we capitalize to challenge the current understanding of motor ability and motor skill.



Figure 1: Our Possi(A)bilities system enables the experience of a video-projected virtual hand on the tabletop in front of a sitting user, where the virtual hand performs movements that are either synchronized with or decoupled from those of the physical hand next to it. By implementing a diversity of possi(a)bilities, *e.g.*, synchronized movements, delayed reaction time, or grasping with a smaller virtual hand, our system encourages reflection on the possible motor abilities of the human hand, readily observed by the user in real time.

Related Work

We relate to prior work from AR and interactive computer systems that have employed the human hand as an I/O surface [6, 16] or used visualizations of the users’ hands as part of interaction techniques [4, 19, 20]. We also relate to art installations that employed images of the human hand.

Visualizations of the user’s hands interacting with a computer system are useful in distributed groupware, where multiple users share the workspace. In VideoArms [19], remote collaborators can see the solid arms of other users, digitally captured by a video camera. KinectArms [4] captures and displays arm embodiments on tabletops using the Kinect sensor, and implements several visual effects, such as shadows and gradients, outlines and transparency, and motion traces. PlayTogether [21] is a video-projection interactive system enabling remote users to play board games and engage in collaborative drawing. IllumiShare [9] is a peripheral device resembling a desk lamp designed to share physical and digital objects on arbitrary surfaces to support collaboration between remote users. Hand visualizations have also been employed in interactive computer systems to assist users when

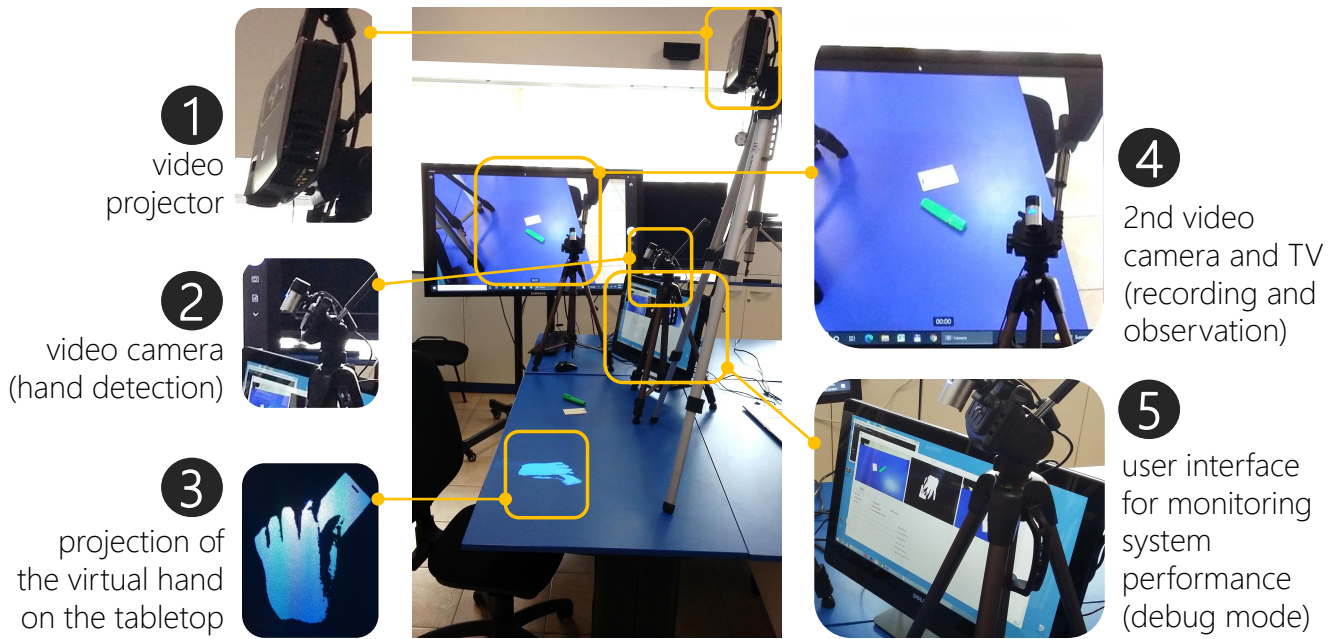


Figure 2: Illustration of the Possi(A)bilities system. On the left, system components creating the Augmented Reality experience for the user: a video projector (1) and a video camera (2) are connected to a PC that controls the virtual hand (3) projected on the tabletop. On the right, system components for debug mode operation: a second video camera (4) for observation and the user interface (5) presenting the results of the various image processing steps, from video acquisition to hand segmentation.

performing or learning specific tasks. For example, Sandnes *et al.* [15] and Rogers *et al.* [13] used video projections on the piano keyboard to support learning piano. Wigdor *et al.*'s [20] “under the table” interaction technique for tabletops makes use of visualizations of the user’s hand positioned under the tabletop to enable touch input from both the top and bottom surfaces of the table. Suzuki *et al.* [18] presented a system that projected virtual hands of experts to serve as guidance for manual workers in factories. Korn *et al.* [11] built a system that video projected instructions directly onto the workspace and evaluated it for people with impairments.

Researchers have also used the human hand as an input/output surface for interactive applications. For example, OmniTouch [6] is a wearable system enabling multitouch interactions on everyday surfaces, including the human hand. A shoulder-worn video camera and projector enable users to draw on the hand, select options from hand-projected menus or interact with applications via controls and UIs projected on the palm of the hand. LightGuide [16] also uses video projection on the hand to guide the user in completing the desired motion, such as during exercises or physical therapy.

In neuropsychology, Suzuki *et al.* [17] implemented an AR version of the rubber hand illusion [2], where movements of the real hand were mirrored by a virtual hand. Rosa *et al.* [14] also used AR to present a virtual hand while both the physical hands were visible to the user, known as the supernumerary hand illusion. Such illusions have been used to understand the experience of body ownership following multisensory integration across the exteroceptive and interoceptive domains.

The expressiveness of human hand functions has been celebrated in art projects employing video projections. Examples include Gary Hill’s “Hand Heard” [7], a five-channel wall-

sized installation showing images of an over-the-shoulder view of a person gazing at one of their hands; Pablo Gnecco’s “Gesture-Gesture” [5] exploring the visual language created with the hands, where three-second videos of hands captured from visitors are video-projected on a wall; and Elina Katara and Sanna-Mari Pirkola’s “Hands (video still images)” [10], where viewers sitting at a table watch video episodes projected onto the surface of a white table cloth: “hands appear in the video and surreal, dream-like things begin to happen.”

Unlike this prior work, the goal of our system is to present users with the experience of a virtual hand that, when aligned with the physical body, demonstrates a variety of possible motor abilities. In this context, possi(a)bilities encourage reflection on what motor abilities and motor skills are in the synchrony between the physical and the virtual.

The Possi(A)bilities System

Figure 2 presents our system, Possi(A)bilities, consisting of a video projector (Dell 3400MP), video camera (Microsoft LifeCam Studio), and a desktop PC (Dell Inspiron 5348, Windows 8.1, Intel Core i5 2.9GHz, 8GB RAM). We developed a custom C# Windows application that detects the user’s hand above the table, processes the image of the hand, records and stores its movements, and projects a virtual hand featuring various visual appearances and behaviors, described next. We employed the Accord.NET framework¹ for image processing, such as background subtraction and binarization to detect the hand against the tabletop and image manipulation to mirror, resize, and reposition the virtual hand inside the projection.

¹<http://accord-framework.net>

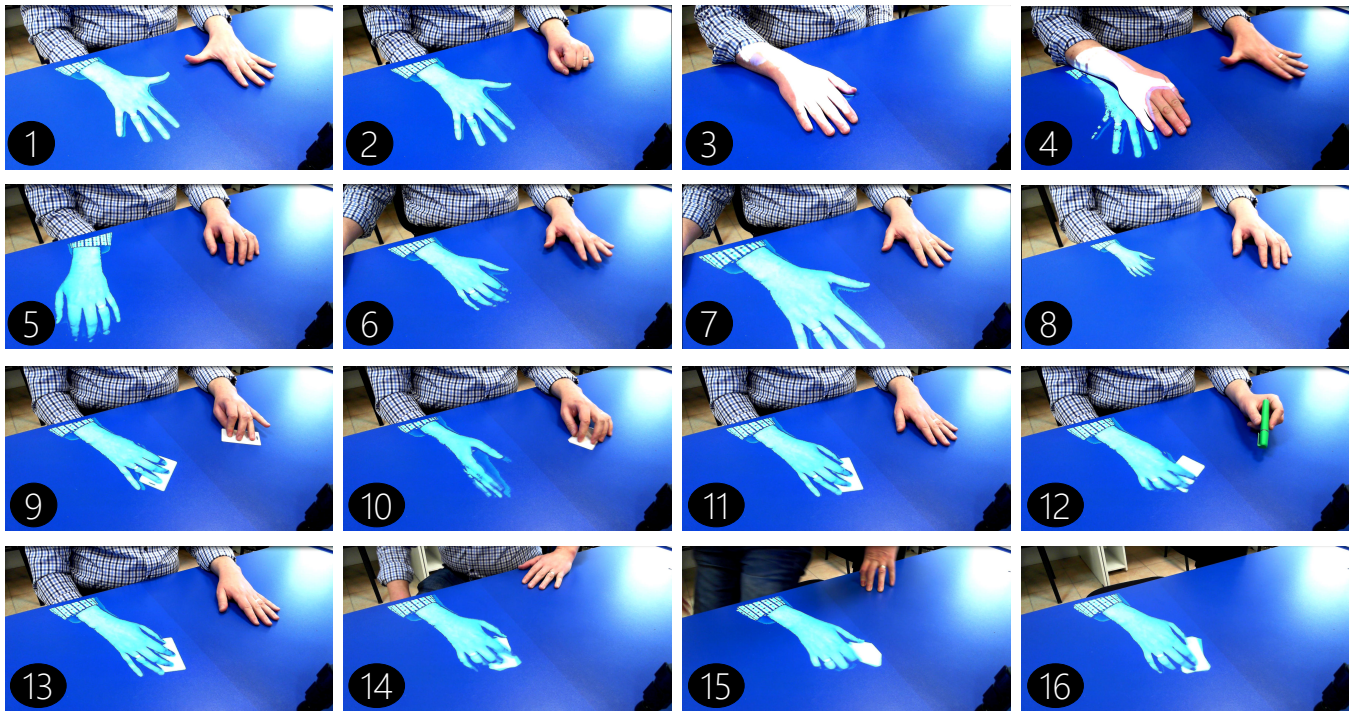


Figure 3: Visualizations of possible motor abilities enabled by a video-projected virtual hand: (1) *mirrored copy*, where the virtual hand mimics the movement of the physical hand; (2) *delayed reaction time*, where the virtual hand replays the movement of the physical hand with a configurable lag; (3) *superposition* with the virtual hand projected on top of the physical hand; (4) *pose decoupling* when the virtual hand is projected on the physical hand, but adopts a different pose; (5) *copy*, the virtual hand is an exact copy of the physical hand; (6) *location decoupling*, the virtual hand is shown at a different location on the tabletop with respect to the user's body; (7) and (8) *size decoupling*, the virtual hand is shown larger or smaller than the physical hand; (9) *synchronized object manipulation*, when the virtual hand mimics the movements of the physical hand manipulating a physical object; (10)-(12) *desynchronized manipulation*, when the virtual hand performs a different action (a recording) compared to the physical hand in relation to the manipulated object; (13)-(15) time-consecutive snapshots of the user leaving the table, while the virtual hand remains in place (16) to perform a recording of the user's most recent action.

The virtual hand represents the image of the user's physical hand, programmed either to mimic the movements of the physical hand or to play a recording. Figure 3 shows several motor abilities illustrated by the virtual hand's movements in conjunction with those of the user's physical hand: mimicking the movement of the physical hand with a one-second lag creates the experience of a delayed reaction time (Figures 3.1 and 3.2); superimposing the virtual hand with a different pose, from a previous recording, suggests motor opportunities for the physical hand (Figure 3.4); a smaller virtual hand aligned with the physical body enables the experience of smaller grasps (Figure 3.8); and playing a video recording with the virtual hand manipulating a postit, while the physical hand holds a pen (Figure 3.12), highlights the intertwining of the physical and the virtual; when the user has left, the virtual hand can persist (Figures 3.13 to 3.16).

Discussion and Future Work

The Possi(A)bilities system engages the user both as an actor and a spectator. As an actor, the user controls the movements of the virtual hand, which mimics the poses and gestures of the physical hand, and the characteristics of its visual appearance, such as the size of the virtual hand. As a spectator,

the user watches how the virtual hand adopts poses and performs movements from a repertoire of previous recordings. The combination of physical–virtual and live–recorded action turns Possi(A)bilities into a medium for exploring, examining, and reflecting on the motor abilities of the human hand enabled by possibilities for human action beyond the physical world and the individual's capacity to act independently. Possi(A)bilities also challenges commonly accepted notions of motor ability [3] and motor skill [12] in hybrid worlds that relax the world's physicality and individuals' agency:

- What specifies motor ability in a physical-virtual space?
- Who owns the motor skill of a virtual hand?
- What new motor abilities and skills are possible with bi-manual synchrony of physical and virtual hands?

Thus, Possi(A)bilities opens several avenues for future work:

- Extend the Possi(A)bilities system to enable interactions between the physical and virtual hands. For example, a physical pen could be used to write on a virtual postit (Figure 3.12), creating a new motor ability available only in the interplay between the physical and the virtual.
- Integrate Possi(A)bilities with control systems, where the virtual hand could be used to interact with physical objects

from the table, *e.g.*, touching a desk lamp with the virtual hand turns on the light, reaching a TV remote control with the virtual hand enables access to the TV. In such application scenarios, the motor abilities of the virtual hand have a physical impact in the physical world.

- Understand user behavior and perceptions regarding the virtual hand visualizations of the Possi(A)bilities system, including users that have lost specific abilities of the hands because of illness or injury, *e.g.*, spinal cord injury that has affected movements of the fingers or wrist.
- Explore Possi(A)bilities for other scenarios besides a tabletop and for other body parts, for example, visualizing a virtual foot projected on the floor next to the user's body.

We look forward to such future explorations towards redefining motor abilities and skills in new physical-virtual worlds.

Acknowledgments

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI-UEFISCDI, project number PN-III-P4-ID-PCE-2020-0434 (PCE29/2021), within PNCDI III.

References

- [1] Anderson, D. I.; Lohse, K. R.; Lopes, T. C. V.; and Williams, A. M. 2021. Individual Differences in Motor Skill Learning: Past, Present and Future. *Human Movement Science* 78:102818.
- [2] Botvinick, M., and Cohen, J. 1998. Rubber hands 'feel' touch that eyes see. *Nature* 391:756.
- [3] Fleishman, E. 1972. On the Relation Between Abilities, Learning, and Human Performance. *American Psychologist* 27(11):1017–1032.
- [4] Genest, A. M.; Gutwin, C.; Tang, A.; Kalyn, M.; and Ivkovic, Z. 2013. KinectArms: A Toolkit for Capturing and Displaying Arm Embodiments in Distributed Tabletop Groupware. In *Proc. of Computer Supported Cooperative Work, CSCW '13*, 157–166. New York, NY, USA: ACM.
- [5] Gnecco, P. 2014. Gesture-Gesture. Available from <http://studiostudio.nyc/gesture>.
- [6] Harrison, C.; Benko, H.; and Wilson, A. D. 2011. OmniTouch: Wearable Multitouch Interaction Everywhere. In *Proc. of the 24th ACM Symp. on User Interface Software and Technology*, 441–450. New York, NY, USA: ACM.
- [7] Hill, G. 1995. HanD HearD. Available from https://garyhill.com/work/mixed_media_installation/hand-heard.html.
- [8] Jones, L. A., and Lederman, S. J. 2006. *Human Hand Function*. Oxford University Press.
- [9] Junuzovic, S.; Inkpen, K.; Blank, T.; and Gupta, A. 2012. IllumiShare: Sharing Any Surface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '12*, 1919–1928. New York, NY, USA: ACM.
- [10] Katara, E., and Pirkola, S.-M. 1998. Hands (video still images). <https://www.elinakatara.net/works/1998-2002/>.
- [11] Korn, O.; Schmidt, A.; and Hörz, T. 2013. The Potentials of In-Situ-Projection for Augmented Workplaces in Production: A Study with Impaired Persons. In *Proc. of CHI '13 Extended Abstracts on Human Factors in Computing Systems*, 979–984. New York, NY, USA: ACM.
- [12] Magill, R. A., and Anderson, D. I. 2014. *Motor Learning and Control: Concepts and Applications (10th Ed.)*. New York, NY, USA: McGraw-Hill.
- [13] Rogers, K.; Röhlig, A.; Weing, M.; Gugenheimer, J.; Könings, B.; Klepsch, M.; Schaub, F.; Rukzio, E.; Seufert, T.; and Weber, M. 2014. P.I.A.N.O.: Faster Piano Learning with Interactive Projection. In *The 9th ACM Int. Conf. on Interactive Tabletops and Surfaces*, 149–158. ACM.
- [14] Rosa, N.; Veltkamp, R. C.; Hürst, W.; Nijboer, T.; Gilbers, C.; and Werkhoven, P. 2019. The Supernumerary Hand Illusion in Augmented Reality. *ACM TAP* 16(2).
- [15] Sandnes, F., and Eika, E. 2019. Enhanced Learning of Jazz Chords with a Projector Based Piano Keyboard Augmentation. In *Proc. of the Int. Conf. on Innovative Technologies and Learning*, 194–203. Cham: Springer.
- [16] Sodhi, R.; Benko, H.; and Wilson, A. 2012. LightGuide: Projected Visualizations for Hand Movement Guidance. In *Proc. of the SIGCHI Conf. on Human Factors in Computing Systems*, 179–188. New York, NY, USA: ACM.
- [17] Suzuki, K.; Garfinkel, S. N.; Critchley, H. D.; and Seth, A. K. 2013. Multisensory Integration Across Exteroceptive and Interoceptive Domains Modulates Self-Experience in the Rubber-Hand Illusion. *Neuropsychologia* 51(13):2909–2917.
- [18] Suzuki, G.; Murase, T.; and Fujii, Y. 2016. Projecting Recorded Expert Hands at Real Size, at Real Speed, and onto Real Objects for Manual Work. In *Companion of the 21st Int. Conf. on Intelligent User Interfaces, IUI '16 Companion*, 13–17. New York, NY, USA: ACM.
- [19] Tang, A.; Neustaedter, C.; and Greenberg, S. 2007. VideoArms: Embodiments for Mixed Presence Groupware. In Bryan-Kinns, N.; Blanford, A.; Curzon, P.; and Nigay, L., eds., *People and Computers*. London: Springer.
- [20] Wigdor, D.; Leigh, D.; Forlines, C.; Shipman, S.; Barnwell, J.; Balakrishnan, R.; and Shen, C. 2006. Under the table interaction. In *The 19th ACM Symposium on User Interface Software and Technology*, 259–268. ACM.
- [21] Wilson, A. D. 2007. PlayTogether: Playing Games across Multiple Interactive Tabletops. In *Proceedings of the IUI Workshop on Tangible Play: Research and Design for Tangible and Tabletop Games*.
- [22] Wobbrock, J. O.; Gajos, K. Z.; Kane, S. K.; and Vanderheiden, G. C. 2018. Ability-Based Design. *Communications of the ACM* 61(6):62–71.

Author Biography

Radu-Daniel Vatavu is a Professor of Computer Science at the University of Suceava, where he directs the MintViz Lab. His research interests include human-computer interaction, ambient intelligence, AR/MR, and accessible computing.