Improving Human-Robot Handover Research by Mixed Reality Techniques

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ABSTRACT

Virtual Reality (VR) and Mixed Reality (MR) have already been incorporated into robotic systems for various applications in the domain of Human-Robot Interaction (HRI), such as telerobotics or as a tool for robotics software development and debugging. In this context, MR techniques allow to enrich the user's experience so that he or she is able to interact with the robot more efficiently. Moreover, robots can be simulated in an immersive VR environment to conduct highly controlled experiments. Close interaction scenarios like handovers, conducted either in the physical or virtual world, have their own inherent limits, e.g., with respect to safety as well as a fixed body structure of the robot in the physical world and degree of realism or level of detail in virtual environments.

Therefore, we explore several MR techniques to overcome these limitations. MR devices, such as the Microsoft HoloLens, allow to augment real environments with visualized sensor data as well as to simulate robotic parts like virtual robot heads or arms attached to a physical robot. This enables HRI experiments that were difficult or impossible to conduct before.

KEYWORDS

Handover, Robot, HRI, Mixed Reality, Virtual Reality, Augmented Reality, Interaction

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1 INTRODUCTION

These days, service robots interact with humans not only in research laboratories, but also outside in the "real world". Thus, robots appear in shopping malls and care facilities where they interact with mostly naive interaction partners. In various human-robot applications MR has been proposed to improve the interaction and support studies.

MR glasses allow to transfer information from the internal representation of the robot to a visualized counterpart displayed in the field of view of the interacting person. This can help to better comprehend and anticipate the robot's behavior. Using entirely virtual environments for highly controlled experiments generates a new range of possibilities with respect to reproducible research. In such immersive experimentation environments even physical limits can be overcome.

In this work we explore the possibilities of MR applied to the example of human-robot handover. Handing objects is a task that requires collaboration and precise synchronization in space and time. While synchronization between two humans happens subconsciously in this task, handovers between a human and a robot still require an explicit protocol. Thus, we present results from a recent handover study and provide suggestions for enhancements utilizing MR techniques. In the following we discuss related work in the fields of MR and human-robot handover. This includes recent work on augmenting sensor data of the robot for the user, virtualizing parts of the robot like the head and simulating the whole robot in an immersive environment.

Mixed Reality Human-Robot Interactions

Virtual Reality and Augmented Reality have been proposed for various applications in the domain of HRI. Already in the 90s AR was suggested for telerobotics: By augmenting a stereo video of the remote robot location the operator's visual perception of the environment could be enhanced facilitating control using virtual pointers and reducing the operators workload [14]. In the area of robotics software development and debugging, MR techniques are already applied especially for the visualization of sensor data. To this end, laser scans and pointclouds from depth cameras, as well as footstep planning were visualized for a humanoid robot [15]. For decoupled testing of algorithms, e.g., in computer vision, a virtual model of the environment can be created [19]. This model provides a virtual ground truth for the robot's physical sensors. In order to evaluate the influence of shape, size and motion of a robot on the impressions and feelings humans have towards them, a robot can be simulated in a Cave Automatic Virtual Environment (CAVE). It was shown that interacting humans reported similar feelings towards real and virtual robots [10]. Other research, however, suggests that a real robot appears to have higher utility, possibility of communication and objective hardness while a virtual robot appears to be more controllable [11].

Apart from professional operators and developers, also naive users profit from MR techniques in HRI. For making robots appear more socially plausible, displaying virtual avatars on physical robots was proposed in [6]. A user survey revealed that people see benefits of using AR for a better understanding of the robot they are working with in an industrial scenario [3]. An example of how this could be achieved is visualizing arrows to signal a robot's

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intended movement to the user [4] for instance. In our current work, the goal is to develop approaches which further facilitate HRI with unexperienced users focussing on human-robot handover scenarios. On the one hand, we use an MR headset for visualizing the robot's perception and integrate its sensor data — laser scans for instance. This way we can, e.g., visualize the workspace in which the robot is able to grasp an object or indicate whether a path is blocked. Moreover, we can dynamically replace parts of the robot's appearance and at the same time have users interact with a real robot. For instance, we can overlay the physical robot head with a customized, more human like, virtual head. On the other hand, by using a simulation in our CAVE, we can evaluate handover strategies in a completely safe and controllable environment while still utilizing the software stack of the real robot.

Human-Robot Handover

Human robot handover research incorporates multiple aspects like generating and optimizing trajectories, detecting and coordinating object transfer and verbal and non-verbal communication. Generating smooth and human-like motions increases the acceptance and predictability of robots: Legible trajectories during collaboration help to decrease the coordination time [5]. Predictable and reactive trajectories can be generated by using dynamic movement primitives as proposed by [16]. Moreover, it was shown that exact timing might be even more important than exact positioning [12]. Hence, the perceived safety was influenced more by timing than by the generated trajectory. Additionally, robots require a mechanism to sense when to grasp and release an object. Existing approaches use, e.g., a force-torque sensor in the robot's wrist to sense contact. By either pulling on the object or by pushing it into the hand of the robot a measurable force is applied [1, 9]. Integrated systems on a mobile service robot have been studied with the result that adaptivity as well as complementary skills of human and robot allow to hand objects to one another [7, 18]. Even though there was progress in this field, robots still need improvement to transfer cognitive and physical load from human to robot.

2 HUMAN-ROBOT HANDOVER STUDY

In previous work we studied human-robot handover with regard to improving alignment and the influence of the human's level of experience [13]. Therefore, we conducted a study on natural human-robot handover with the robot Floka. Floka is depicted in Figure 1 receiving an object from a test subject. The subjects were asked to help the robot learning objects by handing them over one by one. An implementation of wrist-force based handover detection was used for the interaction. To analyze the users' behaviors we used deep-learning techniques to track the users skeleton [20] and automatically annotated the recorded video stream. In our study, performing a prompting gesture with the second arm of the robot did not show any measurable improvement in the synchronization between human and robot. The timing data did not show any significant differences. However, participants that consciously perceived the gesture stated that they perceived the robot more human-like when the robot performed the aforementioned gesture. Significant differences in subject behavior was observed in conjunction with varying levels of prior experience with robots. While naive users

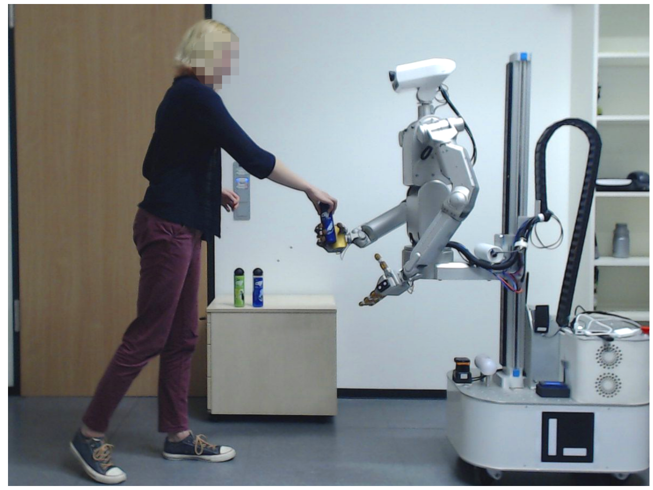

Figure 1: Human-Robot Handover Experiment: The participant takes one of the objects from our robot Floka. A gesture with the left hand of the robot aims to improve synchronization between human and robot.

expected the robot to visually process the environment and react accordingly, experienced users knew that they need to pull and push objects for the robot to sense their intention. Hence, handover capabilities of robots need to adapt more to users in order to cope with the needs of inexperienced users. The elderly and disabled would greatly profit from such developments.

Based on the results of the study we will continue on improving interaction experience for everyone. As robots are not able to move with the same speed and thus exact timing as humans in the near future because of security concerns in such close interactions, other methods like reactive movements and gestures are required to overcome this gap. Another study that could give deeper insides into non-verbal communication cues further investigates the complete body-language instead of the pure trajectory of the end-effector which is transferring the object. This could help the robot to communicate its internal state in a more transparent manner by, e.g., incorporating a second arm for synchronization, gaze strategies, or base orientation.

3 TOWARDS A MIXED-REALITY ROBOT

To thoroughly study the ideal handover between human and robot, we suggest to simulate the robot or parts of it first. We plan to repeat and extend the study described in section 2 with a virtual robot or parts simulated with MR techniques. Planned extensions are faster movements and the incorporation of gaze and facial expressions to foster better alignment and joint understanding of both, human and robot. The models that are extracted from such experiments can then be transfered to the real hardware.

3.1 Augmenting the User's Perspective

Our first step to overcome the knowledge gap between experts and naive users in HRI and especially human-robot handover was to augment the users environment with data visualizing the robot's perceptions and capabilities [17]:

Humans are good at using their own body schema to infer the capabilities of others. They project their body schema on others in cooperative tasks. The body schema of a robot, even if anthropomorphic, is still different from that of a human and naive humans with little experience may have difficulties in estimating where the borders of a reaching space are.

For realizing this idea, we integrated the HoloLens with our Floka robot which is based on the Meka Mobile Manipulator M1. It is operated using a software stack based on ROS. The Unity3D game engine is used for implementation on the MR device. Communication between the MR device and ROS is realized using MQTT. Making use of the room-scale tracking capabilities of the HoloLens, a calibration of the coordinate system of the MR device and the robot is only required initially by scanning a marker attached to Floka. Pose updates of the robot are then used to also update the representation in the HoloLens.

Having the registration done, sensor data is visualized to provide a better understanding of the robot's capabilities. We visualize the map and the robot's localization on it plus the costmap and laser scans for giving sensory information. The planned path is also shown for making the user aware of the next movements. Since the HoloLens is integrated with the robot's coordinate system, it can be used as an additional sensory input device. By this means the robot gains knowledge about the user's position and orientation in the environment. This enables the robot to timely adapt to the user's movements.

For helping the user in handover situations, the robot can visualize where it is able to grasp an object by showing a colored volume (Figure 2, above the hand). This way, the robot can actively ask the user for help, adding information which otherwise would not be obvious. A number of helpful visualizations could be added: the current torque could be shown directly at the wrists and planned grasping trajectories could be visualized. It is possible to highlight recognized objects or the human's hands making sure that the robot is always aware of its interaction partner.

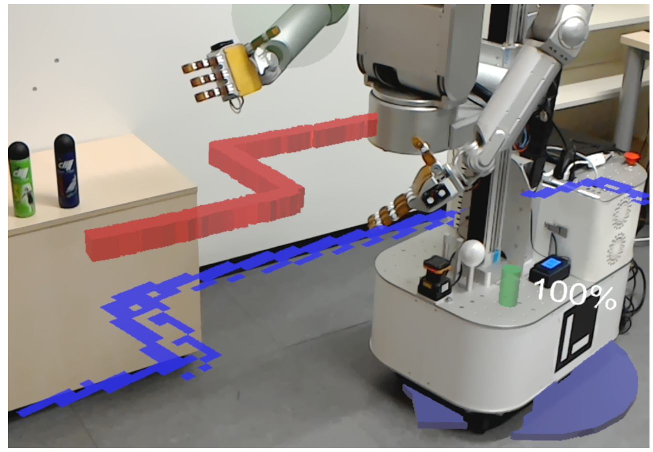

Figure 2: The sensory data visualized in the HoloLens: Map (blue), laser scans (red), the robot's pose(purple) and battery status (battery symbol with white text). Additionally, the space where the robot can sense and receive objects for handover is highlighted with a green sphere above the hand.

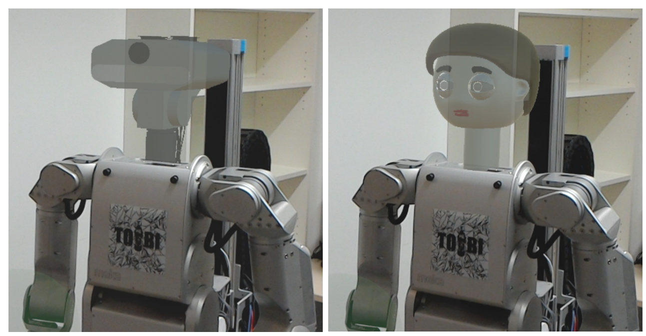

Figure 3: Mixed-reality view from the HoloLens with two different heads on Floka. On the left side is virtual version of the Meka M1 default head. The right picture shows a simulation of the newly developed Flobi head.

3.2 Simulating Parts of the Robot

One aspect for collaboration is creating joint action understanding by communication. Integrating non-verbal cues like gaze and head orientation improves robot-to-human object handover [8]. To evaluate gaze behavior of a robot without physically changing the robot we propose MR as a rapid prototyping approach.

We developed our own robotic head Flobi which is currently reworked to fit the Floka robot. As gaze is a crucial component during collaborative tasks like handover, we propose to study gaze directions and user experience with this head. An evaluation study of robot designs for smart environments [2] has been done with mockups to evaluate the influence of the appearance of the robot's head. Such studies would greatly benefit from MR where the different heads are shown on the real robot in 3D. Figure 3 shows the real robot with two different heads as seen by the user through the HoloLens.

Moreover, we plan on animating the virtual Flobi head providing the same capabilities as the physical version. This way we can evaluate facial expressions and gaze directions during handover before the real robot head is mounted on Floka.

3.3 Simulated Robot in the CAVE

In a recent project we started to simulate the whole Floka robot in a CAVE. Our CAVE is an L-shaped 3D stereo back-projection (passive Infitec) environment. This allows the user to immersively interact with the robot. The user is tracked by a 10-camera OptiTrack Prime 13W system, which is capable of skeleton as well as rigid-body tracking. Figure 4 shows the virtual Floka receiving a box from Patrick. The virtual environment allows us to produce postures and movements of the robot that might either mirror the real robot or even enhance the capabilities of the real robot.

Performing tasks with physical objects in a virtual environment is still a challenging task. Transferring the object between a human and a completely virtual robot might interfere with the immersion.

Figure 4: A virtual Floka displayed in the CAVE is receiving an object from Patrick. For the picture stereo was disabled and the perspective was corrected for the camera and not the interacting user.

However, it is possible to measure the reaction time and evaluate whether the users understand the robots intentions. In addition the immersion can be improved with haptic gloves or a controller that has a virtual object attached.

4 CONCLUSION

In this work, we present MR applications in the context of object handover with the robot Floka. In a recent study, we found significant differences in behavior of subjects with varying levels of prior experience with robots during a handover task. Subsequently, we propose techniques that help to understand robots and support research in this area. To this end, augmentation of robot sensors could help the user to put themselves in the position of the robot. Moreover, by using a virtual robot we have (almost) no limits with respect to movement speed and accelerations. Thus, we are able to perform robot movements that currently only humans are able to perform. However, it remains challenging to simulate direct interaction with a fully virtual robot. Tactile gloves or force feedback controllers need to be added to simulate an object and contact with the robot. Future work will show how these might influence the interaction.

By virtualizing body parts of the robot like its head, we present a way to perform a handover with the real hands while improving joint attention with an enhanced robotic head that is able to show facial expressions. Combining real robots with mixed reality techniques contributes to the overall goal of making robots easier to read and use by everyone.

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REFERENCES

[1] Mohamad Bdiwi, Jozef Suchy, and Alexander Winkler. 2013. Handing-over model-free objects to human hand with the help of vision/force robot control. In *10th International Multi-Conferences on Systems, Signals & Devices 2013 (SSD13)*. IEEE, 1–6. https://doi.org/10.1109/SSD.2013.6564138

[2] Jasmin Bernotat and Friederike Eyssel. 2017. An Evaluation Study of Robot Designs for Smart Environments. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction (HRI '17)*. ACM, New York, NY, USA, 87–88. https://doi.org/10.1145/3029798.3038429

[3] Rainer Bischoff and Johannes Kurth. 2006. Concepts, Tools and Devices for Facilitating Human-Robot Interaction with Industrial Robots through Augmented Reality. In *ISMAR Workshop on Industrial Augmented Reality, October*, Vol. 22.

[4] Michael D. Coovert, Tiffany Lee, Ivan Shindev, and Yu Sun. 2014. Spatial augmented reality as a method for a mobile robot to communicate intended movement. *Computers in Human Behavior* 34, Supplement C (May 2014), 241–248. https://doi.org/10.1016/j.chb.2014.02.001

[5] Anca D Dragan, Shira Bauman, Jodi Forlizzi, and Siddhartha S Srinivasa. 2015. Effects of Robot Motion on Human-Robot Collaboration. *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction - HRI '15* 1 (2015), 51–58. https://doi.org/10.1145/2696454.2696473

[6] Mauro Dragone, Thomas Holz, and Gregory M.P. O'Hare. 2006. Mixing Robotic Realities. In *Proc. of the 11th Int. Conference on Intelligent User Interfaces (IUI '06)*. ACM, New York, NY, USA, 261–263. https://doi.org/10.1145/1111449.1111504

[7] Aaron Edsinger and Charles C. Kemp. 2007. Human-robot interaction for cooperative manipulation: Handing objects to one another. *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication* (2007), 1167–1172. https://doi.org/10.1109/ROMAN.2007.4415256

[8] Elena Corina Grigore, Kerstin Eder, Anthony G. Pipe, Chris Melhuish, and Ute Leonards. 2013. Joint action understanding improves robot-to-human object handover. In *IEEE International Conference on Intelligent Robots and Systems*. 4622–4629. https://doi.org/10.1109/IROS.2013.6697021

[9] Wuwei He and Daniel Sidobre. 2015. Improving Human-Robot Object Exchange by Online Force Classification. *Journal of Human-Robot Interaction* 4, 1 (2015), 75. https://doi.org/10.5898/JHRI.4.1.He

[10] K. Inoue, S. Nonaka, Y. Ujiie, T. Takubo, and T. Arai. 2005. Comparison of human psychology for real and virtual mobile manipulators. In *IEEE International Workshop on Robot and Human Interactive Communication, 2005. ROMAN 2005*. 73–78. https://doi.org/10.1109/ROMAN.2005.1513759

[11] H. Kamide, M. Yasumoto, Y. Mae, T. Takubo, K. Ohara, and T. Arai. 2011. Comparative evaluation of virtual and real humanoid with robot-oriented psychology scale. In *2011 IEEE International Conference on Robotics and Automation (ICRA)*. 599–604. https://doi.org/10.1109/ICRA.2011.5979893

[12] Ansgar Koene, Anthony Remazeilles, Miguel Prada, Ainara Garzo, Mildred Puerto, Satoshi Endo, and Alan M Wing. 2014. Relative importance of spatial and temporal precision for user satisfaction in human-robot object handover interactions. *Third International Symposium on New Frontiers in Human-Robot Interaction* 14 (2014).

[13] Sebastian Meyer zu Borgsen, Jasmin Bernotat, and Sven Wachsmuth. 2017. Hand in Hand with Robots: Differences between Experienced and Naive Users in Human-Robot Handover Scenarios. In *Lecture Notes in Artificial Intelligence (LNAI).*, Abderrahmane Kheddar, Eiichi Yoshida, Shuzhi Sam Ge, Kenji Suzuki, John-John Cabibihan, Friederike Eyssel, and Hongsheng He (Eds.), Vol. 10652. Springer., 587–596. https://doi.org/10.1007/978-3-319-70022-9_58

[14] Paul Milgram, S. Zhai, D. Drascic, and J. Grodski. 1993. Applications of augmented reality for human-robot communication. In *Proceedings of the 1993 IEEE/RSJ International Conference on Intelligent Robots and Systems '93, IROS '93*, Vol. 3. 1467–1472 vol.3. https://doi.org/10.1109/IROS.1993.583833

[15] Koichi Nishiwaki, Kazuhiko Kobayashi, Shinji Uchiyama, Hiroyuki Yamamoto, and Satoshi Kagami. 2008. Mixed reality environment for autonomous robot development. In *IEEE International Conference on Robotics and Automation, 2008*. IEEE, 2211–2212. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4543538

[16] Miguel Prada, Anthony Remazeilles, Ansgar Koene, and Satoshi Endo. 2014. Implementation and experimental validation of Dynamic Movement Primitives for object handover. *IEEE International Conference on Intelligent Robots and Systems* (2014), 2146–2153. https://doi.org/10.1109/IROS.2014.6942851

[17] Patrick Renner, Florian Lier, Felix Friese, Thies Pfeiffer, and Sven Wachsmuth. 2018. Facilitating HRI by Mixed Reality Techniques. In *HRI '18 Companion: 2018 ACM/IEEE International Conference on Human-Robot Interaction Companion*. ACM/IEEE. https://doi.org/10.1145/3173386.3177032

[18] E. A. Sisbot and R. Alami. 2012. A Human-Aware Manipulation Planner. *IEEE Transactions on Robotics* 28, 5 (2012), 1045–1057. https://doi.org/10.1109/TRO.2012.2196303

[19] Michael Stilman, Philipp Michel, Joel Chestnutt, Koichi Nishiwaki, Satoshi Kagami, and James Kuffner. 2005. Augmented reality for robot development and experimentation. *Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, Tech. Rep. CMU-RI-TR-05-55* 2, 3 (2005).

[20] Shih-En Wei, Varun Ramakrishna, Takeo Kanade, and Yaser Sheikh. 2016. Convolutional pose machines. In *Conference on Computer Vision and Pattern Recognition*.