VTT

beyond
the obvious

EuroXR 2021

Proceedings of the Virtual EuroXR Conference

Kaj Helin | Jérôme Perret | Sara Arlati (eds.)

VTT TECHNOLOGY 395

VTT TECHNOLOGY 395

EuroXR 2021

Proceedings of the Virtual EuroXR Conference

Kaj Helin (ed.)

VTT Technical Research Centre of Finland Ltd

Jérôme Perret (ed.)

EuroXR Vice-President for EU issues and Collaboration, Haption CEO
France/Germany

Sara Arlati (ed.)

EuroXR 2021 Application Chair, CNR-STIIMA, Italy

Graphical design & Technical editing: Päivi Vahala-Partanen
VTT Technical Research Centre of Finland Ltd

VTT

ISBN 978-951-38-8756-8

VTT Technology 395

ISSN-L 2242-1211
ISSN 2242-122X (Online)
DOI: 10.32040/2242-122X.2021.T395

JULKAISIJA – PUBLISHER

VTT
PL 1000
02044 VTT
Puh. 020 722 111
https://www.vtt.fi

VTT
P.O. Box 1000
FI-02044 VTT, Finland
Tel. +358 20 722 111
https://www.vttresearch.com

EuroXR 2021: Milan, Italy

The focus of virtual EuroXR 2021 conference is on novel VR/AR/MR technologies, including software systems, display technology, interaction devices, and applications. Besides papers on the latest scientific results and highlights from many application fields, the EuroXR conference series aims at creating a unique framework, interconnecting European and international XR communities, for knowledge cross-fertilisations between researchers, technology providers, and end-users.

24-26 November 2021

Milan, Italy

Conference organizers

STIIMA

Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato

Consiglio Nazionale delle Ricerche

EUROXR

VTT

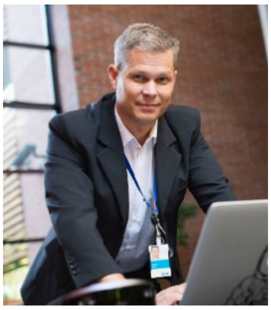
Preface

We are pleased to present these conference proceedings in the VTT Technology series, which contains the papers accepted for the Application and Exhibition & Demo Track of EuroXR 2021, the 18th annual EuroXR conference, be hosted by CNR-STIIMA institute on 24-26 November 2021 as a virtual conference. This publication is thus a collection of the application papers (talks, posters and demonstrations) presented at the conference. It provides an interesting perspective into current and future applications of VR/AR/MR.

In previous years, under the name EuroVR, the conference has been held in Bremen (2014), Lecco (2015), Athens (2016), Laval (2017), London (2018), Tallinn (2019), and Valencia (2020The focus of the EuroXR conferences is to present, each year, novel Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR) technologies, including software systems, display technologies, interaction devices, and applications, to foster engagement between industry, academia, and the public sector, and to promote the development and deployment of VR/MR/AR technologies in new, emerging, and existing fields. This annual event of the EuroXR association (https://www.euroxr-association.org/) provides a unique platform for exchange between researchers, technology providers, and end users around commercial or research applications.

We would like to warmly thank the industrial committee chairs for their great support and commitment to the conference, and special thanks go to the local organizing committee for their great effort in making this event happen ☺.

On behalf of the organising committee,



Kaj Helin

VTT

EuroXR EC member and Principal Scientist at VTT Technical Research Centre of Finland Ltd., Finland

Jérôme Perret

haption

EuroXR Vice-President for EU issues and Collaboration, Haption CEO France/Germany

Sara Arlati

STIIMA

EuroXR 2021 Application Chair, CNR-STIIMA, Italy

Table of contents

EuroXR Application Program Chairs

- Sara Arlati (STIIMA, CNR, Italy)
- Lorenzo Cappannari (AnotherReality, Italy)
- Kaj Helin (VTT, Finland)
- Andrey Lunev (XR Insight Europe, Amsterdam, The Netherlands)
- Jérôme Perret (Haption, France & Germany)
- Krzysztof Walczak (Poznań University of Economics and Business, Poland)

EuroXR Demo and Exhibition Chairs

- Vera Colombo (STIIMA, CNR, Italy)
- Giannis Karaseitanidis (ICCS, Greece)
- Matthieu Poyade (GSA, UK)
- Arcadio Reyes-Lecuona (University of Malaga, Spain)

EuroXR General Chairs

- Luca Greci (STIIMA, CNR, Italy)
- Hideo Saito (Keio University, Japan)
- Bruce H. Thomas (Director of IVE Lab, University of South Australia)

EuroXR Scientific Program Chairs

- Mariano Alcañiz Raya (Immersive Neurotechnologies Lab, Spain)
- Patrick Bourdot (University paris-Saclay, CNRS, VENICE team, France)
- Pablo Figueroa (Los Andes University, Colombia)
- Victoria Interrante (University of Minnesota, USA)
- Regis Kopper (University of North Carolina, USA)
- Torsten W. Kuhlen (RWTH Aachen University, Germany)
- Dirk Reiners (University of Central Florida, USA)

EuroXR Organizing Team

- Daniele Dalmiglio, Francesca Sacchini (STIIMA, CNR, Italy)
- Marco Sacco, Beatrice Palacco, & Patrick Bourdot (EuroXR)

Applications

The Remote User Test of Mixed Reality System for AIT/AIV in the Space Domain

Kaj Helin[1], Jaakko Karjalainen[1], Timo Kuula[1], Paul Kiernan[2],

Gianluca Casarosa[3], and David Martinez Oliveira[3]

[1]VTT Technical Research Centre of Finland Ltd, Tampere, Finland

[2]SKYTEK Ltd, Dublin, Ireland

[3]ESA – European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands

Corresponding author: kaj.helin@vtt.fi

Keywords:

Mixed Reality, Space Domain, HoloLens 2, mobiPV, Assembly, Integration, Testing and Verification

Introduction

This extended abstract introduces the Mixed Reality (MR) system which has been developed for assembly, integration, testing and verification (AIT/V) in the space domain. It has been developed in two European Space Agency's (ESA) projects called: (1) "AROGAN - Augmented reality-based orbit and ground applications" and (2) "VirWAIT - Virtual Workplace for AIT & PA Training and Operations Support". The MS HoloLens 2 mixed reality platform (Microsoft, 2021) was integrated as novel user interface to the ESA Mobile Procedure Viewer system called mobiPV (Boyd et al., 2016).

MR and/or Augmented Reality (AR) has been tested within several projects of the space domain in the fields of training and manual work support (Tedone et al., 2016). Also, MR and/or AR usability has reach acceptable level in the space related high knowledge manual works support (Helin et al., 2018).

The preliminary user review of the first integrated prototype of mixed reality tools was done remotely due to COVID-19 situation. Testing group was located at ESA – ESTEC, and developer / evaluation team was following test from Finland and Ireland. Test case was the installation of thermocouples on the Solar wind Magnetosphere Ionosphere Link Explorer – SMILE (SMILE, 2021).

The remote user test had two goals: (1) To receive initial feedback from the test users for the improvement of the MR-system, and (2) to test the online remote review procedure.

Remote user test

The preliminary user review of the first integrated prototype of MR tools was done in April 2021 and there were two test subjects. The user test was remotely due to COVID-19 situation and traveling restrictions. Testing group was located at ESA – ESTEC, and developer team was following test via Microsoft Teams from Finland and Ireland. Test case was the installation of thermocouples on the first configuration of the heating plate designed for the thermal test of SMILE.

The MR-systems which was used in remote user test was including:

(1) Microsoft HoloLens 2 with AR-player app, (see Figure 1– left),

(2) mobiPV – server for all Operations Data File (ODF) ((NASA, 2010) content and 3D models

(3) mobiPV's web interface, which also allows to the user interact with systems.

The test procedure was prepared using the systems 'offsite' authoring environment which utilized a CAD model of the SMILE system to define MR elements.

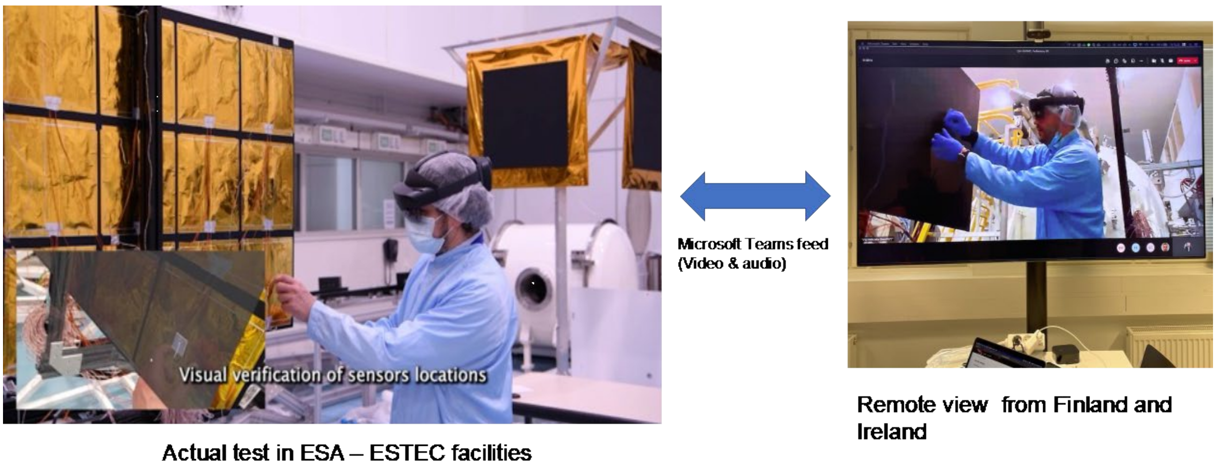


Figure 1. The set-up for the remote user test of the MR system. Left: Actual system installation in ESA-ESTEC. Right: Video and audio feed for observation teams in Finland and Ireland

User were able to see in 3D space information related to each procedure step e.g., 3D models, images, text information, symbol annotations, …, and user was interacting with system with voice commands and gestures. Evaluation was performed remotely via Teams and following methods was exploited: (1) think-aloud, (2) observations and (3) interviews after the tests.

Conclusion and discussion

The mixed reality system for AIT/AIV was seen as useful for the work support and its usability was on acceptable level, albeit further development is required. Also, remote user evaluation was working quite effectively, even though technical expert is required in test facility.

Acknowledgment

This study has been funded by ESA under contracts: 4000127710/19/NL/GLC "Procedure viewer and authoring tool for ground AIV/AIT applications" and 4000129549/19/NL/BJ "Virtual Workplace for AIT & PA Training and Operations Support"

References

Boyd, A., Fortunato, A., Wolff, M. & Martinez Oliveira, D. (2016). mobiPV: A new, wearable real-time collaboration software for Astronauts using mobile computing solutions. SpaceOps 2016 Conference 16-20 May 2016, Daejeon, Korea. https://doi.org/10.2514/6.2016-2306

Helin, K., Kuula, T., Vizzi, C., Karjalainen, J., & Vovk, A. (2018). User Experience of Augmented Reality System for Astronaut's Manual Work Support. Frontiers in Robotics and AI, 5(SEP), [106]. https://doi.org/10.3389/frobt.2018.00106

Microsoft HoloLens mixed reality platform, https://www.microsoft.com/en-us/HoloLens, last accessed 2021/08/21.

National Aeronautics and Space Administration (2010). Operations Data File Standards, Report SSP50253, Revision R, Houston, Texas, NASA Johnson Space Center.

SMILE, Solar wind-Magnetosphere-Ionosphere Link Explorer, https://www.cosmos.esa.int/web/smile, last accessed 2021/08/21.

Tedone, D., Marello, M., Musso, G., Frangakis, N., Martinez Oliveira, D., Agostinho, S., & Helin, K. (2016). Augmented Reality for the Support of Space Exploration Missions and On-Ground/On-Orbit Operations. In Advances in Human Factors and System Interactions (pp. 141-151). Springer. https://doi.org/10.1007/978-3-319-41956-5_14

Appendix

Video from the remote user tests: https://youtu.be/gefrH8EJXWU

Augmented Reality Interface for Industrial Robot Control and Teleoperation

Laura Ordile[1], Yevhen Bondarenko[1], Simone Luca Pizzagalli[1], Vladimir Kuts[2], and Tauno Otto[1]

[1]*Tallinn University of Technology, Department of Mechanical and Industrial Engineering, Estonia*

[2]*University of Limerick, Department of Electronic and Computer Engineering, Ireland*

Corresponding author: simone.pizzagalli@taltech.ee

Keywords:

Augmented reality, User interface, Ateleoperation, Industrial robot, Digital twin

Introduction

Intuitive and natural user interfaces (UI) are part of the technologies required in advanced manufacturing and modern industrial systems (Berg & Ju, 2020). Operators tend to be more and more involved in a user centered working environment, performing tasks side by side, simultaneously or in a collaborative way with automated robots. In this context, interfaces become a central design topic which allow reliable control on the systems and the integration of human interaction and machine control in the same design scope (Pizzagalli et al., 2021). This work presents an augmented reality (AR) user interface for robotic arm control and teleoperation through gesture manipulation allowing the end-user to visualize the industrial robot digital twin (DT) in a real-world scenario while controlling the real synchronized machinery placed at Tallinn University of Technology in Estonia.

Materials

The presented system leverages on the DT discussed in (Kuts et al., 2019). The robotic arm employed in the application is the Motoman GP8 DT and its real counterpart located in Tallinn university of Technology Mechanical and Industrial Engineering Demo Center as shown in Figure 2.

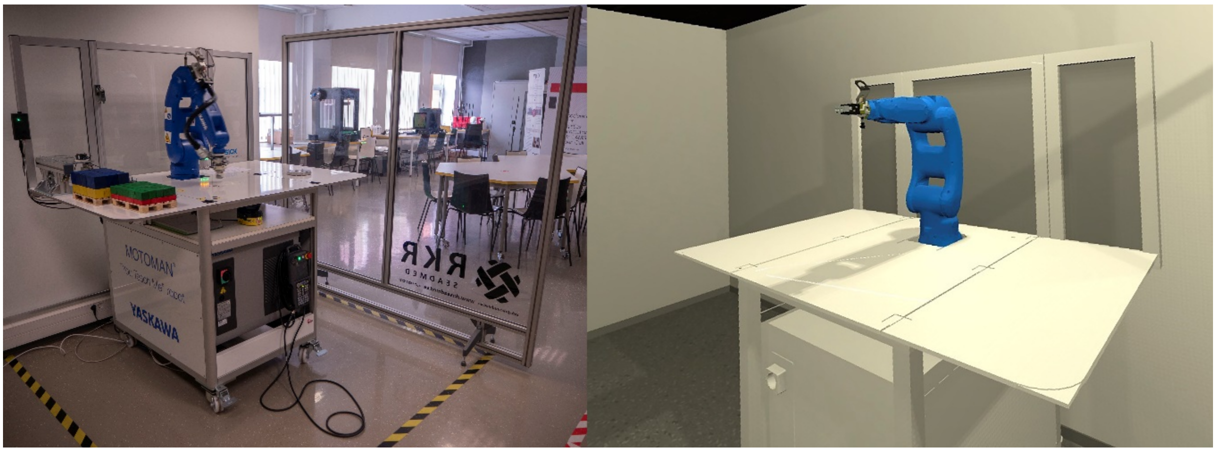


Figure 2. The Motoman GP8 industrial robotic arm and its Digital Twin.

The visualization and interaction hardware used for this demo application is Hololens 2. This AR head mounted display provides the user with augmentation of real-world scenarios by means of see-through holographic lenses. Hololens 2 integrates several sensors such as head tracking, eye tracking, inertial measurement unit, microphone, and a depth sensor. These allow the user to engage with the augmented content interaction trough different channels. The DT application is developed in Unity and makes use of MRTK (Mixed Reality Toolkit), Vuforia Engine and MQTT protocol. MRTK is an open-source toolkit including functionalities aimed at input system, hand and eye tracking, UI controls and spatial awareness. MRTK is primarily used to implement the object manipulation and interface interactable elements. Vuforia is employed for target-based placement of the augmented 3D content in the real environment. Vuforia Engine SDK for Unity allows the creation of augmented reality content aimed iOS, Windows and Android devices and based on different types of targets such as QR codes, image, object, and environmental. The presented application uses a simple image target to localize the robot arm and connected interface in the real-world scenario. MQTT provides a reliable and efficient publishing-subscribing based messaging protocol between the DT and real-world machinery. MQTT is widely used in many different contexts such as manufacturing, smart environments, or consumer products. The integration and development of the MQTT connection and protocol in Unity is extensively presented in (Kuts et al., 2017). The architecture of the system in shown in Figure 3.

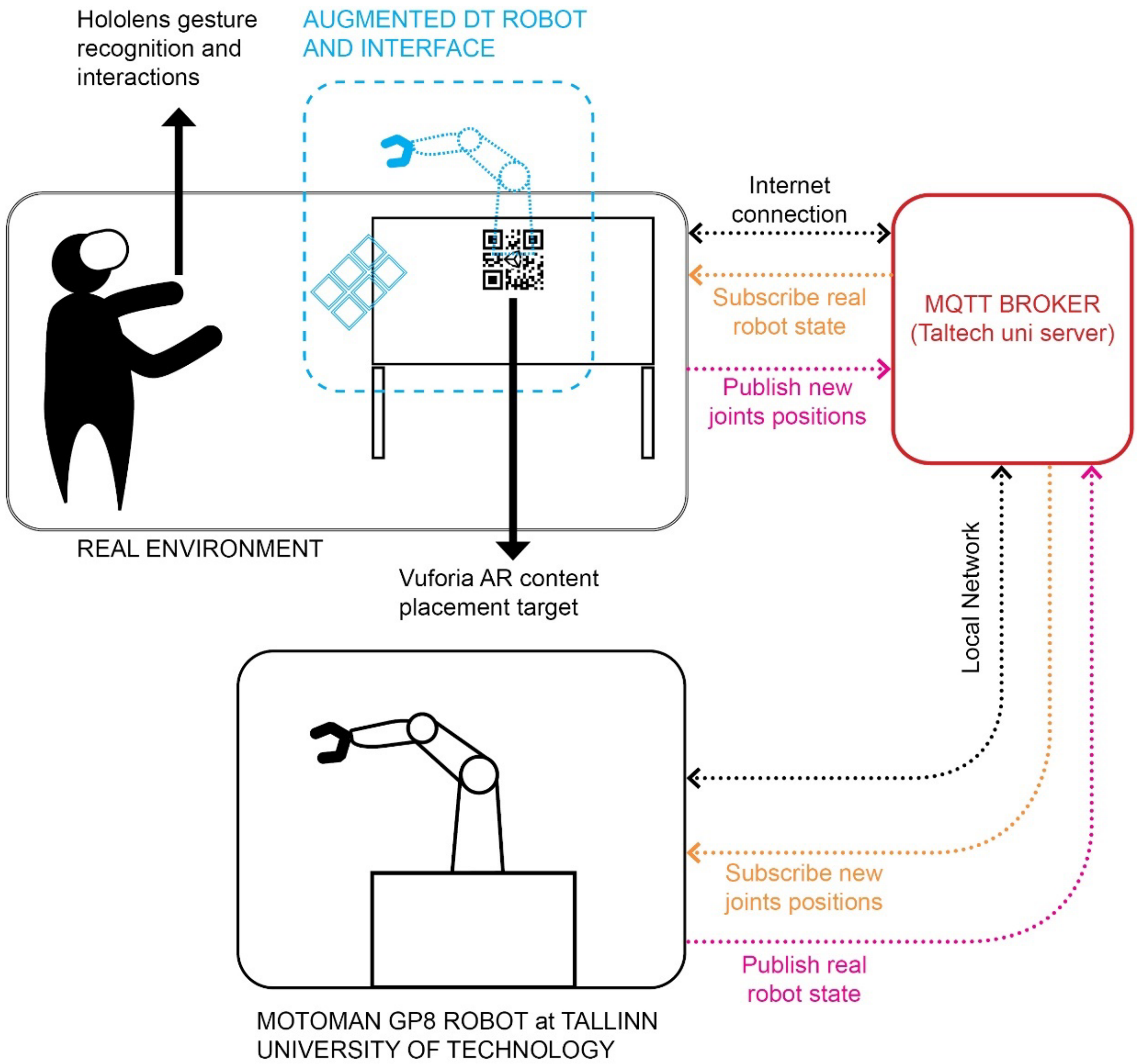


Figure 3. Proposed system architecture

DT AR interface functionalities

The developed application allows the user to visualize the Motoman GP8 as a hologram overlapped to the abovementioned image target which enables the positioning of the 3D model in the real-world scenario though Vuforia Engine target recognition, Figure 4.

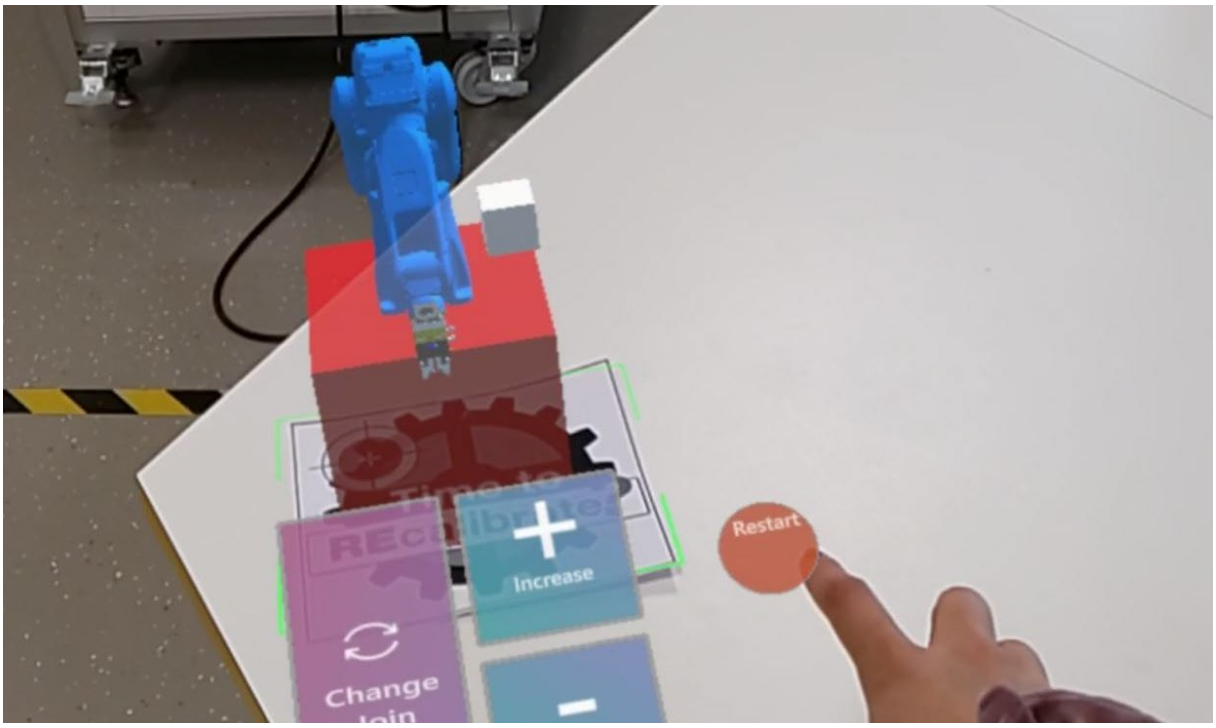


Figure 4. The AR DT interface target based positioning.

The augmented model can be further manipulated by means of the build in HoloLens 2 pinch and zoom hand recognition gestures. The user is therefore able to move, enlarge or downsize the virtual robot in the real working space, Figure 5.

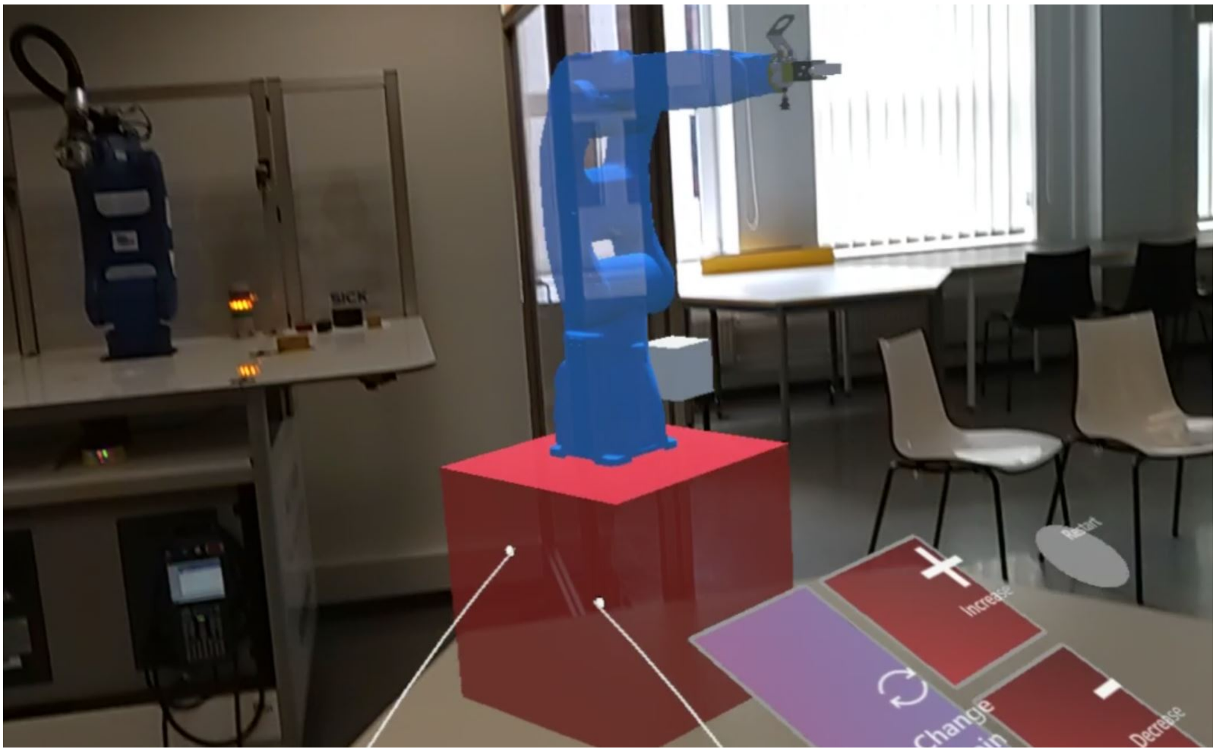


Figure 5. Resizing and moving the AR interface and robot

The robot AR interface is connected to the DT as shown in the previous images and allows the simple control of the robot joints by means of tapping or clicking gesture on top of the AR interface elements. Four buttons have been implemented and allow to switch between the

Motoman GP8 joints and increase or decrease the angle for each of them. A restart button allows to reset all joint positions to zero. The real robot joint positions are updated and synchronized by means of the MQTT protocol as explained in Figure 3.

Conclusion and future works

The application provides a simple yet reliable AR UI for industrial robot control and teleoperation allowing the user to be aware of the real-world environment while interacting with the DT counterpart of advanced industrial machinery over the internet and from remote locations. Future developments will encompass extended functions for the interfaces, including synchronized mode, joints speed and gripper interactions controls. The use of different gestures will be explored as much as the efficient integration and coexistence of virtual and real objects in the operator workspace and field of view.

References

Berg, J., & Lu, S. (2020). Review of interfaces for industrial human-robot interaction. *Current Robotics Reports*, *1*(2), 27-34.

Pizzagalli, S. L., Kuts, V., & Otto, T. (2021). User-centered design for Human-Robot Collaboration systems. In *IOP Conference Series: Materials Science and Engineering. 1140*(1), 012011). IOP Publishing.

Kuts, V., Otto, T., Tähemaa, T., & Bondarenko, Y. (2019). Digital twin based synchronised control and simulation of the industrial robotic cell using virtual reality. *Journal of Machine Engineering*, 19, 128-144.

Kuts, V., Modoni, G, E., Terkaj, W., Toivo, T., Sacco, M., & Otto, T. (2017). *Augmented Reality, Virtual Reality, and Computer Graphics* vol 10324, (De Paolis, L. T., Bourdot, P., & Mongelli, A. (Eds.). Cham: Springer International Publishing.

A Study on Shadow Removal for Viewing Direction Dependent Appearance Manipulation

Yudai Matsumoto, and Toshiyuki Amano

Graduate School of Systems Engineering, Wakayama University, Japan

Corresponding authors: s226258@wakayama-u.ac.jp, & amano@wakayama-u.ac.jp

Keywords:
Spatial Augmented Reality, Occlusion, Adaptive Radiometric Compensation

Abstract

The light-field feedback system proposed by Amano et al. realized individual appearance manipulation according to the viewing direction. The system consists of multiple projector-camera pair which placed toward to projection target, and the observer is supposed to observe from the outside of the system. However, it has a problem that the system blocks the observer's view, and it is preferable to observe in front of the projector-cameras. This paper investigates the viewing direction-dependent appearance manipulation behavior for the case observer blocks the projection and capture. In addition, we discuss how to optimize the projections.

Introduction

Spatial Augmented Reality (SAR), which augments the real world by using projected light from a projector (Raskar et al., 2001) has been widely applied to projection mapping events and theme park attractions, and it has attracted a lot of attention. Since then, not only various projection techniques such as dynamic projection mapping, projection on deformable objects, high-speed projection, multispectral projection, and light field projection have been proposed (Grundhöfer et al., 2018).

Amano et al. have proposed a system that can manipulate the appearance of an object according to each viewing direction (Viewing Direction-Dependent Appearance Manipulation: VDDAM) using multiple projector-camera pairs (Amano et al., 2017). Since this method does not consider the overlapping of projections, the manipulation error remains. In contrast, Murakami et al. proposed a system that can manipulate the appearance according to the viewing direction based on the reflectance matrix (Murakami & Amano, 2018) In this method, the target image is set in a specific lighting environment, so it is affected by the ambient light. To solve this problem, Amano et al. proposed a VDDAM based on multiple projector-camera feedback employed the reflectance matrix (Amano & Yoshioka, 2020). It achieved a viewing direction appearance manipulation with a light field-feedback (LFFB) by taking advantage of both methods. However, since such VDDAM requires multiple projectors

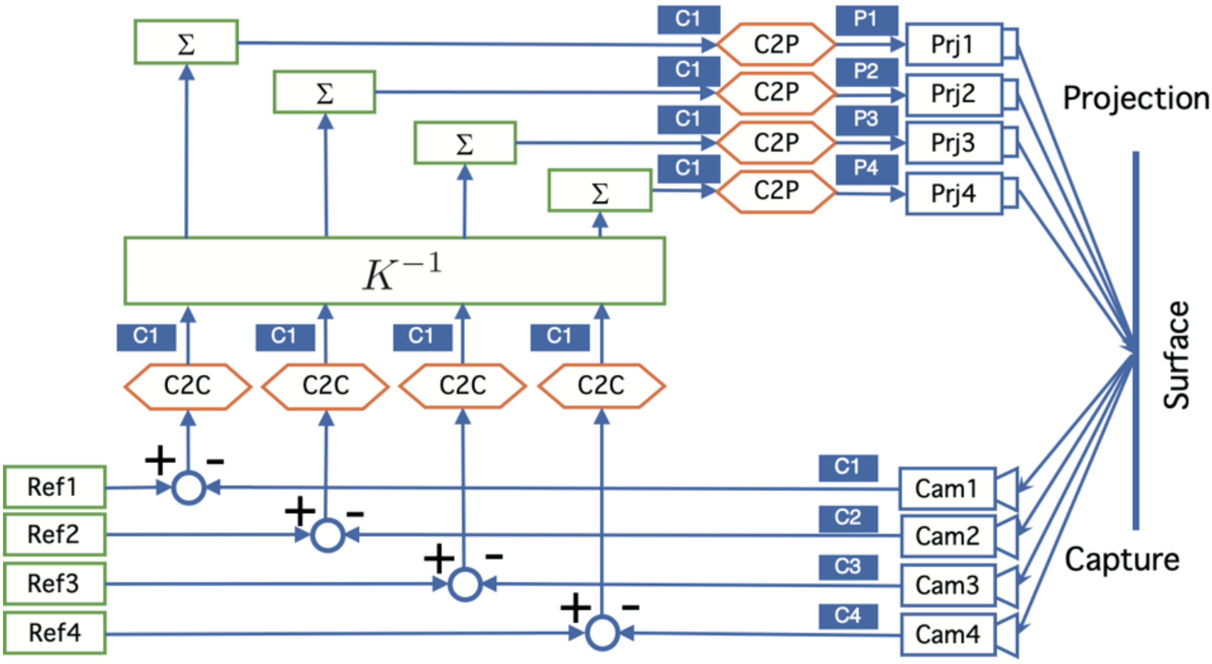


Figure 6. Light-field feedback system for the VDDAM

in front of the projection target, these projectors block the observer's view. Otherwise, observers block projection illumination when they enter in front of the projector. With the detection of the shadow, the system potentially removes shadow with a collaborative projection (Jaynes et al., 2004) and a Passive Virtual Rear Projection (Sukthankar et al., 2001) achieved dynamic shadow removal. Such projection can be implemented with tracking (Audet & Cooperstock, 2007), one-shot image (Sugaya et al., 2010), synthetic aperture capturing (Iwai et al., 2014). However, the key question is the potential for VDDAM. The following sections investigate the VDDAM behavior and discuss how to optimize the projections.

VDDAM based on light-field feedback

In Amano & Yoshioka (2020), a light-field feedback system is designed to compensate for the manipulation error due to environmental illumination change by the expansion of the appearance manipulation framework (Sukthankar et al., 2001), as shown in Figure 6. The system consists of four projectors and four cameras, and they achieve a VDDAM by the light-field feedback with signal decoupling K^{-1}, as follow:

1. Capture an image on each camera Cam1, ..., Cam4.
2. Calculate the control error from the reference image Ref$i$ for all Cam$i$.
3. Reshape Cam$i$ by pixel mapping C2C and unify the geometrical shape.

4. Apply decoupling by K^{-1} and update each projection image by Σ.
5. Project Prj$i$ after the geometrical reshaping by C2P.

Evaluation of VDDAM robustness on occluded situation

In this chapter, we investigate the robustness of VDDAM using LFFB when an obstruction is placed between the projector and the projection target. In this experiment, we use the LFFB system consisting of four cameras and four projectors and investigate the manipulation error when the projection or capturing is blocked by the obstruction placed at each of the positions shown in Figure 7, Figure 8 shows the manipulation reference (Reference: color phase shift) and target appearance under the white illumination, manipulation result with Amano's method in no occluded situation. As shown in Figure 9, cast shadows appeared on the projection target when we placed the obstacle on the table. We confirmed less affected results (e.g., Position3) and serious results (e.g., Position1) depending on the obstacle position.

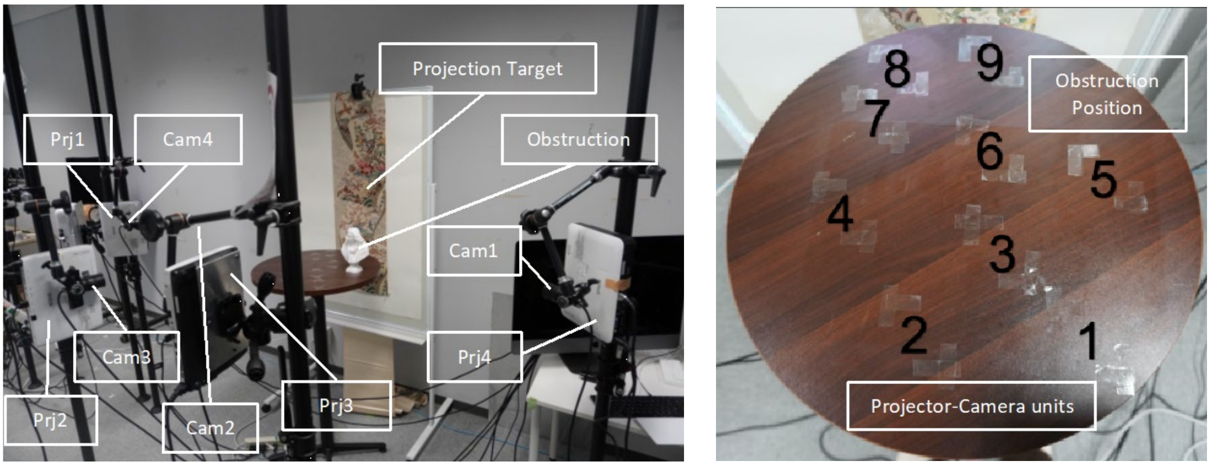


Figure 7. Experimental setup and obstruction position

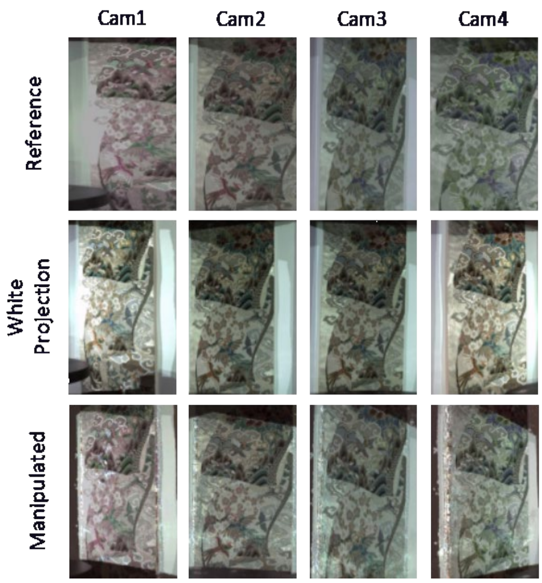


Figure 8. No occluded situation

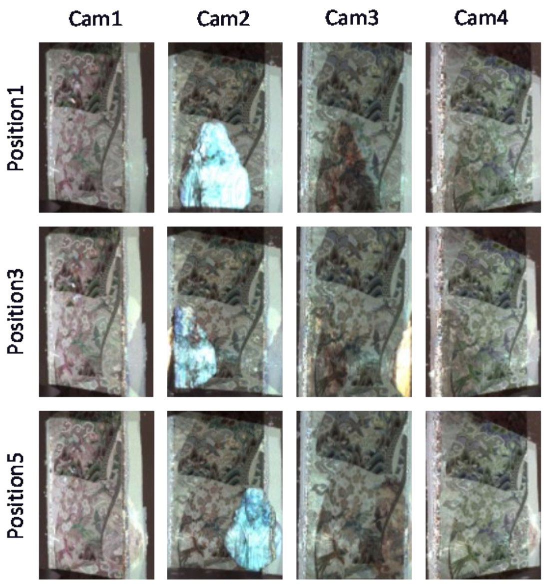


Figure 9. Occluded situations

Discussion

Shadow Creating Process

In the case of Position1 shown in Figure 9, the obstacle blocked projection from Prj3 and resulting in a strong shadow from the Cam3 viewpoint. Besides, the projection makes a bright appearance of obstacle image on the Cam2 image, and it makes projection on the obstacle going to brighter. Since the LFFB is performed with decoupling K^{-1}, the projection control at the manipulation point on the projection target is responsible for the one captured image based on the reflection property K. Therefore, cooperative projection cannot remove shadow by its mechanism. This problem should be solved in our future work.

Possibility of VDDAM on the Occluded Situation

A possible systematic solution is a rank reduction of K that removes unreachable projector and camera according to the situation on each point on the manipulation target. It depends on the reflection property or degree of freedom of manipulation, but we believe the VDDAM is possible under its restriction. For this reduction, we need a dynamic obstacle detection employed in the Passive Virtual Rear Projection.

Conclusion

This paper investigated the VDDAM behavior for the case observer blocks the projection and capture. The experimental results confirmed that the VDDAM proposed by Amano et al. produces serious shadows on the target object. In contrast, we also confirmed less affected results depending on the obstacle position. In the future, we implement rank reduction with obstacle detection to remove cast shadow for the VDDAM.

References

Amano, T., Ushida, S., & Miyabayashi, Y. (2017). Dependent appearance-manipulation with multiple projector-camera systems. In *Proceedings of the 27th International Conference on Artificial Reality and Telexistence and 22nd Eurographics Symposium on Virtual Environments*, pp. 101-107.

Amano, T., & Yoshioka, H. (2020). Viewing-Direction Dependent Appearance Manipulation Based on Light-Field Feedback. In *Proceedings of the International Conference on Virtual Reality and Augmented Reality*, pp. 192-205.

Audet, S., & Cooperstock, J. R. (2007). Shadow Removal in Front Projection Environments Using Object Tracking. In *Proceedings of the 2007 IEEE Conference on Computer Vision and Pattern Recognition*, pp. 1-8.

Iwai, D., Nagase, M., & Sato, K. (2014). Shadow removal of projected imagery by occluder shape measurement in a multiple overlapping projection system. *Virtual Reality*, 18(4), 245-254. https://doi.org/10.1007/s10055-014-0250-4

Jaynes, C., Webb, S., & Steele, R. M. (2004). Camera-based detection and removal of shadows from interactive multiprojector displays. *IEEE Transactions on Visualization and Computer Graphics*, 10(3), 290-301.

Grundhöfer, A., & Iwai, D. (2018, May). Recent advances in projection mapping algorithms, hardware and applications. In *Computer Graphics Forum*. 37(2), 653-675. https://doi.org/10.1111/cgf.13387

Murakami, K., & Amano, T. (2018). Materiality manipulation by light-field projection from reflectance analysis. In *Proceedings of the International Conference on Artificial Reality and Telexistence and Eurographics Symposium on Virtual Environments*, pp. 99-105.

Raskar, R., Welch, G., Low, K. L., & Bandyopadhyay, D. (2001, June). Shader lamps: Animating real objects with image-based illumination. *In Proceedings of the Eurographics Workshop on Rendering Techniques*, pp. 89-102. Springer, Vienna.

Sugaya, Y., Miyagawa, I., & Koike, H. (2010). Contrasting shadow for occluder light suppression from one-shot image. *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*, pp. 96-103. https://doi.org/10.1109/CVPRW.2010.5544603.

Sukthankar, R., Cham, T. J., & Sukthankar, G. (2001). Dynamic shadow elimination for multi-projector displays: In *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition. CVPR 2001*. II151-II157. https://doi.org/10.1109/CVPR.2001.990943.

XR Based GUI Concept for BIM Digital Twin Data Visualization

Kaj Helin[1], Vladimir Goriachev[1], Jaakko Karjalainen[1], Timo Kuula[1], Marja Liinasuo[1], and Matthias Aust[2]

[1]VTT Technical Research Centre of Finland Ltd, Tampere/Espoo, Finland

[2]Fraunhofer-Institute for Industrial Engineering IAO, Stuttgart, Germany

Corresponding author: kaj.helin@vtt.fi

Keywords:

BIM, Digital Twin, GUI, eXtented Reality

Introduction

This extended abstract introduces the eXtented Reality (XR) based graphical user interface (GUI) concept for the construction of Digital Twin Model. The abstract also describes Augmented Reality (AR) tool called BIM@Construction, which is part of GUI concepts and visualizes digital twin data on a construction site. Work has been done in a European Commission funded H2020 project called "BIMprove - Improving Building Information Modelling by Realtime Tracing of Construction Processes" (BIMprove, 2021).

XR based graphical user interface concept

The construction Digital Twin Model has various layers and users with different needs and requests for information. There is no 'one-fit-for-all' GUI for all user roles and needs. The BIMprove's general GUI concept can be seen in Figure 10. The GUI concept has four modes:

1) Digital Twin mode
2) Immersive Digital Twin mode
3) Mobile mode
4) Notification and Warnings mode

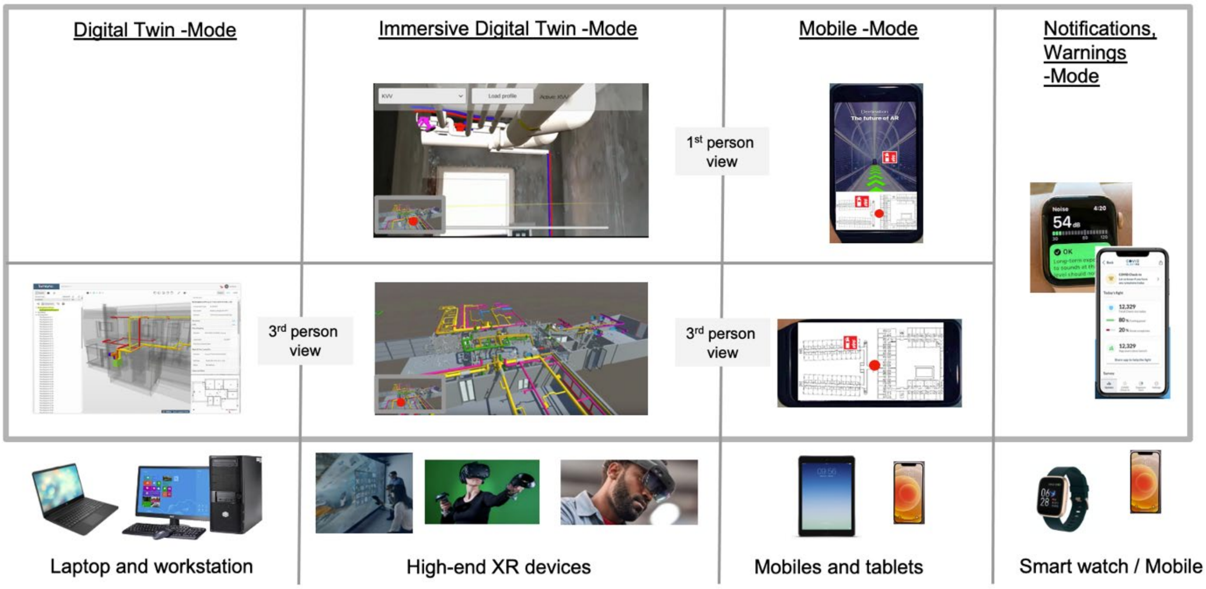


Figure 10. BIMprove's general-level UI concept, to be used in various devices.

User is able to change modes based on device features and user-profile-based access rights. User can have the 1st person or 3rd person view in Immersive Digital Twin and Mobile modes. Digital Twin mode allows user to exploit only the 3rd person view. In the 1st person view, user will see information from the digital twin in real scale, i.e., can feel as if being located in a real room in Virtual Reality. In the 3rd person view, user can see information from digital twin in free distance, e.g., zoom in and out in a 2D map. There are mini maps on the 1st person or 3rd person views, which support user's orientation on the BIMprove Digital Twin model and elicit better situation awareness. The most urgent and relevant information will be given to user via Notification and Warning mode.

BIM@-Categories

Besides the general UI concept which classifies the different UIs by their *modes* of use – whether it's 1st-or 3rd-person view and the features of the used devices, in the BIMprove-project, there is also the categorization by *context* of use, which leads to the following six categories: BIM@Contructrion, BIM@Emergency, BIM@OffSiteOffice, BIM@Vehicle, BIM@Anywhere, and BIM@SiteOffice. This has already been described in Aust et al. 2020, especially the last one, BIM@SiteOffice. This present abstract focusses on the first category of this list, BIM@Contruction.

BIM@Construction

To evaluate and test BIMprove GUI concept, the first function prototype was developed. The protype was called BIM@Construction. It is supporting Immersive and mobile AR features, which are described in sub sections.

Immersive AR

Main idea behind BIM@Construction concept application is to use BIM as digital twin data in immersive XR devices at the construction site. While AR devices like Microsoft HoloLens 2 (Microsoft, 2021) are already built for interaction with 3D models (as shown in Figure 11), scale of those models is usually dictated by the FOV (Field of View) of the headset. In order to overlay digital twin information on top of the real building, additional pivot objects should be created. Naturally, pivot object placement should match the placement of the fiducial markers in the real world. That way the digital twin and its real-world counterpart will be located in the same coordinate system. BIM@Construction includes several tools, which user can use in 1st person mode, like notes, measure tools, warning signs etc.

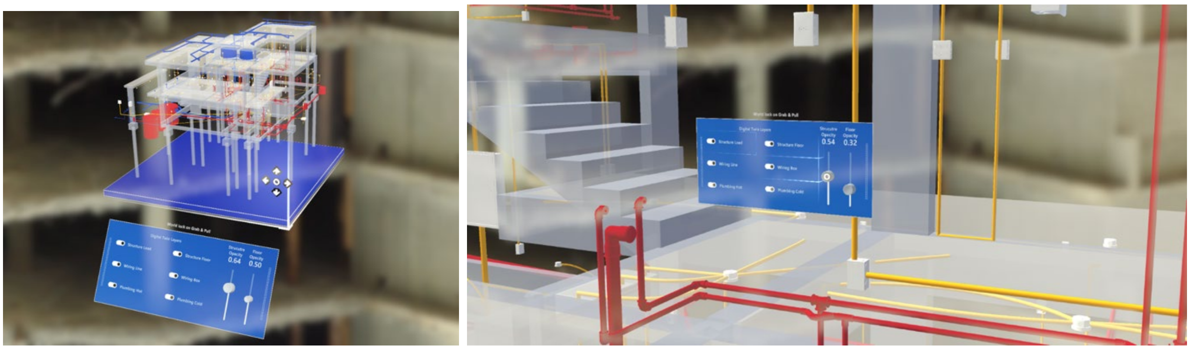


Figure 11. Immersive AR version of BIM@Construction. Left: 3rd person view. Right: 1st person view

Mobile AR

The mobile mode version of BIM@Construction concept application (see Figure 12) is using computer vision for feature and plane detection in order to place AR-based object in the scene. It doesn't necessarily need fiducial markers but works well with them since they can be used for on-site tracking and contain additional image features (texture and contrast variation). In the same way as a HoloLens 2 application, the tablet version of the mobile mode provides both the 1st and the 3rd person views.

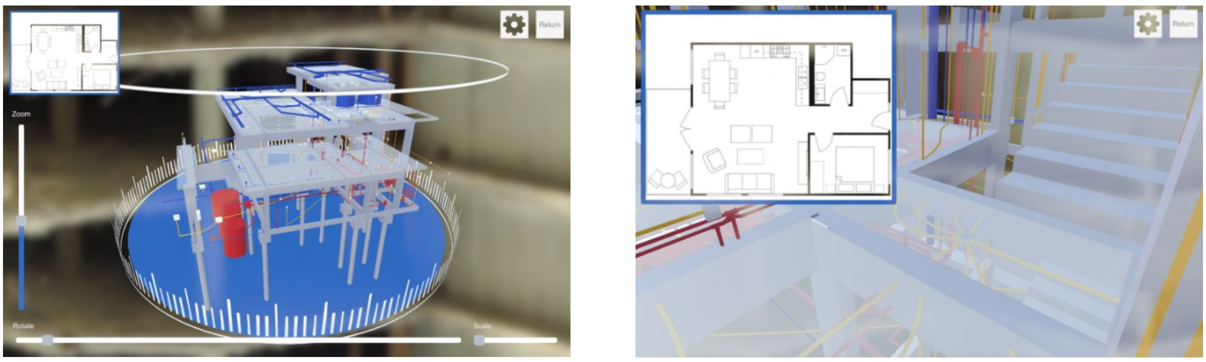


Figure 12. Mobile mode version of BIM@Construction. Left: 3rd person view.
Right: 1st person view

Conclusion and next steps

Based on the first functional prototype testing, developed XR based GUI concept seems to be working properly. It also allows user to see various information levels based on user roles. In next phase, new tools will be developed based on user needs.

Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958450.

References

Aust, M., Otto, M., Helin, K. (2020). BIMprove User Interfaces: Multi-User-XR for construction (Poster). In: Helin, K., de Antonio, A., Reyes-Lecuona, A. (Editors): *EuroVR 2020 Application, Exhibition & Demo Track: Proceedings of the Virtual EuroVR Conference*, ISBN 978-951-38-8741-4, 71-75.

BIMprove, CORDIS, https://cordis.europa.eu/project/id/958450, last accessed 2021/08/21.

Microsoft HoloLens mixed reality platform, https://www.microsoft.com/en-us/HoloLens, last accessed 2021/08/21.

Appendix

Video from the remote user tests: https://youtu.be/T87hhU8yqM8

Multi-User-XR for Digital Twin Data in Construction

Matthias Aust[1], Jan-Filip Kvrgic[1], Jörg Frohnmayer[2],

Melissa Otto[2], and Kaj Helin[3]

[1]*Fraunhofer-Institute for Industrial Engineering IAO, Stuttgart, Germany*

[2]*University of Stuttgart, Institute of Human Factors and Technology Management, Germany*

[3]*VTT Technical Research Centre of Finland Ltd, Tampere/Espoo, Finland*

Corresponding author: *matthias.aust@iao.fraunhofer.de*

Keywords:

Building Information Modeling, Digital Twin, Graphical User Interface, eXtended Reality, Virtual Reality, Multi-user

Introduction

This extended abstract describes a multi-user-VR-system (later multi-user-XR) developed within the European Commission funded H2020 project called "BIMprove - Improving Building Information Modelling by Realtime Tracing of Construction Processes" (BIMprove, 2021). It is an update on last year's EuroVR application track poster "BIMprove User Interfaces: Multi-User-XR for construction" (Aust et al., 2020).

The BIMprove Project

The focus of the EU-H2020-project "BIMprove" is to exploit the advantages of Building Information Modeling (BIM) during the construction phase of a building by turning the BIModel of the planning phase into a digital twin of the building, which is then updated daily throughout the construction and used for easier planning, construction management, and hazard avoidance. It will also later benefit the operation of the building.

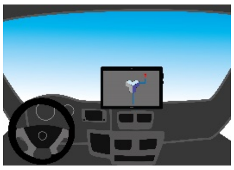
BIM@-Categories

The BIMprove-System, with the digital twin of the construction at its core, will have many different user interfaces (UIs) to be used by a very diverse group of users in different contexts. Which is why in the project, these UIs are divided by their context of use into the following six categories.

BIM@Construction

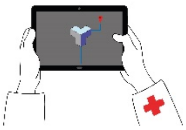
First functional prototypes of BIM@Construction-UIs have already been implemented. It supports immersive and mobile AR features on the construction site, for example to make future installations visible or installations "hidden" inside a wall.

BIM@Vehicle



This category covers the use of BIMprove from a vehicle. This, for example, could be a truck driver navigating the construction site or a crane operator checking the current 3D-model.

BIM@Emergency

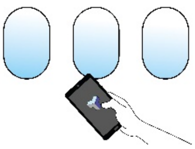


One of the BIMprove-project's major goals is to improve both the avoidance of and the reaction to emergency situations. The BIM@Emergency category encompasses UIs to support both these goals. Possible user roles in this category are personnel of the construction company such as health and safety specialists, and emergency professionals, such as fire fighters and paramedics.

BIM@OffSiteOffice

To maintain the digital twin of the construction as the single source of truth throughout the construction process, the BIMprove-System needs to make it possible for planner engineers to make changes to their plans, when requested. This they will be able to do from their own offices.

BIM@Anywhere



BIMprove will be a cloud-based system. This UI category facilitates accessing it from anywhere via a mobile device. The difference to other categories of UIs, where the expected main devices will also be smartphones and tablets, are the user roles and the tasks.

BIM@SiteOffice

In Aust et al. (2020) we introduced "...the idea of a multi-user, multi-device XR-system to be set up at a construction site, for both co-located and remote use." This system comprises both, the context of using the BIMprove-System from the construction site office and joining a multi-user-session from another office, the construction site itself, or from anywhere via mobile device.

This is symbolized in Figure 13. A first prototype of this has been implemented and tested. This prototype is described in the following section.

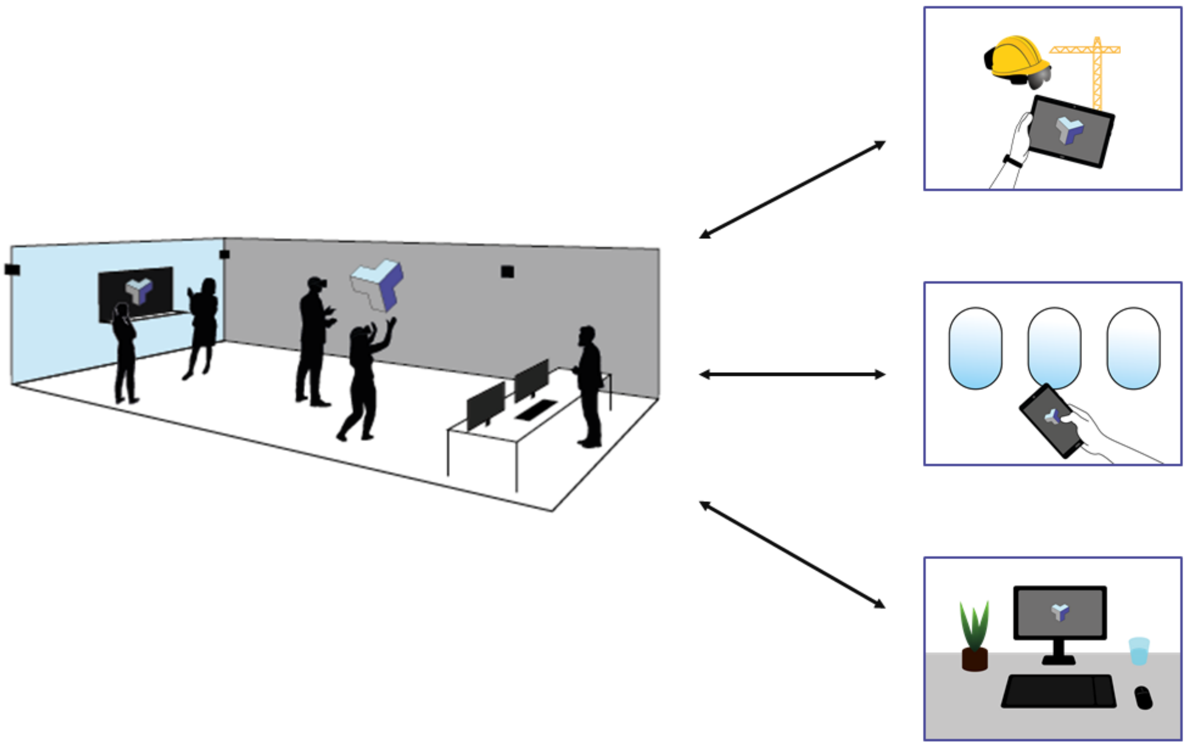


Figure 13: The construction site office and its "satellite"-systems

Multi-User and Multi-Device XR

The first prototype of the BIMprove multi-user systems enables multiple users to remotely join a session to inspect a BIModel, either with a VR-HMD or from a Desktop PC. The PC version is used like a computer game where the user can navigate with the keyboard to fly through the 3D world. Is has the same functionality as the VR version which is as follows:

- Navigation: The users can travel ("fly") through the model using their controllers and a point-and-fly interaction technique with a rubberband-physics-metaphor.
- (De-)selection of models: Depending on how the model is subdivided, e.g. into discipline-models or by floors, the users can hide and unhide these sub-models to inspect different aspects using a hand-UI and the controllers (see Figure 14 below).

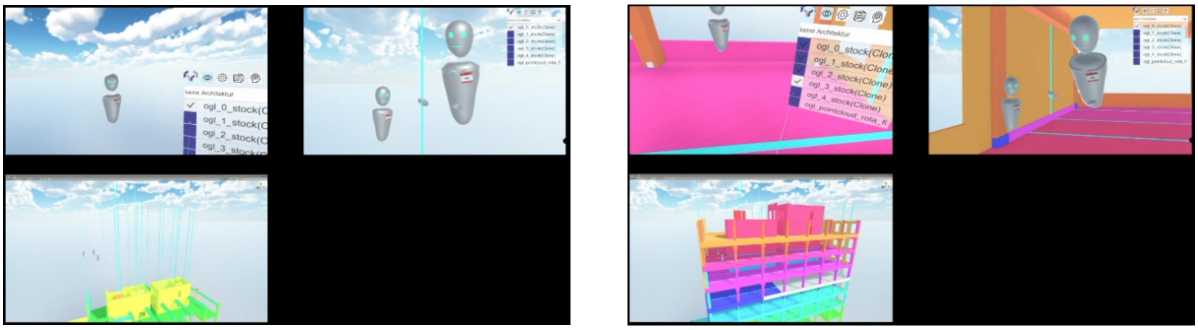


Figure 14. Screenshots showing the simultaneous view of VR- and PC-users -- notice the visible hand-GUI virtually attached to VR-users' controllers that, synchronized between users, shows which storeys are set visible and which are not.

- Communication: The users can see each other's avatars; They can also see when an avatar is talking, hear each other via voice chat, and use a virtual laser pointer to show each other things in the model.
- Issue management: The system also contains the first version of functionalities for issue creation and management. With their controllers and the hand-UI users are able to create and position question marks in the model that represent issues -- these (and most likely other symbols, depending on the nature of the issue) will, in the future, be connected to BCF-issues (BIM Collaboration Format). Currently, an issue can be created, given 3D-coordinates by positioning the question mark, edited via menu, and deleted again. The functionalities related to issue management will surely be revised, amended, and be subject to user tests many times throughout the project, as they are among the most important features of this user interface.
- Communication about issues: Since a likely use case for Multi-User-VR will be to, as a group, go through the list of issues one by one to discuss them, there is also the functionality to
    - a) click on an issue in the list to jump (navigate) to it directly, and
    - b) summon everyone in the session to an issue in the list in order to discuss this certain issue.
    - This last functionality is new and has not yet been user-tested.

First Usability Tests

This first prototype of the BIMprove XR-Viewer has been tested in simple usability tests with four users. Each test-user had a single session to try out the different functionalities described above, and then another session with another test-user as a partner to test multi-user-functionality. The test-users were asked to think aloud during the tests, give feedback in interviews and fill out questionnaires. The general feedback was very positive even though some of the interaction techniques were reported to be a little notchy, still. The System Usability Scale averaged at 76, which ranks between "good" and "excellent".

Conclusions and further Developments

The XR-Viewer is used for Multi-User-VR, as it now stands. It is planned to facilitate joining a Multi-User-session with AR-HMDs and other devices, as well -- hence the name XR-Viewer. The first results are promising but the first prototype needs to be tested with "real" users from construction companies. The BIMprove project will offer that opportunity.

Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958450.

References

Aust, M., Otto, M., Helin, K. (2020). BIMprove User Interfaces: Multi-User-XR for construction (Poster). In: Helin, K., de Antonio, A., Reyes-Lecuona, A. (Editors): *EuroVR 2020 Application, Exhibition & Demo Track: Proceedings of the Virtual EuroVR Conference*, ISBN 978-951-38-8741-4, 71-75.

BIMprove, CORDIS, https://cordis.europa.eu/project/id/958450, last accessed 2021/08/21.

A Prototype for the Treatment of Children with Selective Mutism using Interactive 360° VR

Khalid Azougagh, Jesse van den Berge, and Robert G. Belleman

Computational Science Laboratory, Informatics Institute, University of Amsterdam, The Netherlands

Corresponding author: R.G.Belleman@uva.nl

Keywords:

Selective Mutism, Anxiety Disorder, Virtual Reality, Exposure Therapy, 360° VR

Abstract

"Selective mutism" is an anxiety disorder in which a child is unable to speak in certain situations. In collaboration with psychologists and therapists from Amsterdam University Medical Center (AUMC), the Academic Center for Child & Adolescent Psychiatry ("Levvel") and Erasmus Medical Center, a project was carried out to design and implement a prototype for a VR exposure therapy application as an addition to the regular treatment of young children with selective mutism. An evaluation of the prototype among therapists shows the prototype has potential but that more work must be done before the application can be used autonomously by actual patients.

Introduction

"Selective mutism" is an anxiety disorder where a child consistently is unable to speak in situations where it is expected to (such as at school) where the child is able to talk in others (such as at home). Children with selective mutism frequently communicate non-verbally by nodding or shaking their heads. Noteworthy is that girls are nearly twice as likely as boys to be affected by selective mutism (Carbone et al., 2010). Selective mutism has a low prevalence and is therefore often not recognized or not recognized in time. This is distressing because if left untreated, selective mutism can have a highly disruptive impact on a child's education and social and emotional development, in some cases resulting in leaving school early, limited future prospects, and complex, chronic anxiety and mood problems. Also, the disorder can be solved through treatment. Experts from the Academic Center for Child & Adolescent Psychiatry ("Levvel") and the Amsterdam University Medical Center (AUMC) are specialized in the treatment and scientific research of selective mutism in the Netherlands. They have developed an innovative behavioral treatment protocol for selective mutism among children (Güldner, et al., 2010).

The primary objective of the work presented here is to develop a prototype of a Virtual Reality Exposure Treatment (VRET) application that can augment the therapy used to treat selective mutism. In collaboration with therapists and researchers from AUMC and Levvel, this application is designed to lower the anxiety of young children thereby enabling them to talk when expected. The application allows children to practice in a virtual school situation just prior to the actual real-life situation, where otherwise a therapist would practice with the child at a location and time that is often far from where and when it is needed. The VRET application presents a realistic, child-friendly, and interactive experience that adds value to the current face-to-face treatment. In addition, the environment records patient progress (securely and safely) in a way that therapists can monitor the effectiveness of the treatment.

We describe the design considerations and implementation of this application and evaluate its efficacy based on the feedback from professional therapists.

Literature study

This work relates to two distinct fields of research: exposure therapy and available technologies to support these treatments. The scientific literature has shown that exposure-based therapies effectively treat anxiety. In addition, the literature using VR technology for similar treatments has been reviewed.

A literature study has been conducted to gain a clear understanding of the anxiety disorder selective mutism. Furthermore, VR technology, including 360° video, and its possibilities are explored, providing a solid basis for the design phase in which the requirements have been defined.

Human anxieties and phobias come in a wide variety of types. It is part of the natural development of children if they experience anxiety in situations that are perceived as threatening. However, when the anxiety is intense and persistent and interferes with children's development, it is called an anxiety disorder (Abramowitz et al., 2010; Scholing & Braet, 2002). In the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), selective mutism is classified as an anxiety disorder (American Psychiatric Association, 2013). This classification forms the treatment protocol’s foundation for selective mutism (Güldner et al., 2010).

Exposure therapy is an effective approach for treating anxiety disorders, where the patient is exposed to real-life settings that are perceived to be anxious. There are several types of exposure therapy, including in vivo, flooding, and imagery. In vivo entails a gradual exposure approach that progressively seeks out more difficult and fearful real-life situations. On the other hand, flooding immediately exposes the person to the most fearful situation (Scholing & Braet, 2002). Imagery exposure is a treatment method in which the patient is guided to imagine being exposed to anxious conditions gradually (Wiederholdet al., 2002).

Visualization problems during imagery exposure can impede treatment while losing control during in vivo exposure is a risk. VRET can overcome these obstacles (Pallavicini et al., 2013). VRET is based on in vivo exposure therapy, which is confronting anxiety in a virtual, realistic environment that adapts naturally to the user's head and/or body motion (Parsons & Rizzo, 2008). In the scientific literature, several Randomized Controlled Trials (RCTs) and meta-analysis studies show that VRET appears to be as beneficial as in vivo in the treatment of anxiety disorders (Parsons & Rizzo, 2008; Anderson et al., 2013; Kampmann et al., 2016; Bouchard et al., 2016; Powers & Emmelkamp, 2008). More interesting and relevant here is that an important aspect is addressed where further research is required in developing animated virtual environments as opposed to real filmed environments. The latter is considered more visually realistic, but the lack of interaction makes the situation less immersive (Emmelkamp et al., 2020). In a comparison study of the two VR technologies, no difference in efficacy was observed. However, real filmed environments, also known as Live-Action VR, were preferred because it was perceived significantly more realistic and provided a stronger experience. In contrast, the animated VR environment may appear unrealistic and experienced as a video game (Powers et al., 2018). The level of immersion depends rather on two factors: "Place Illusion" which is the feeling of being in a virtual environment despite the knowledge of not actually being there, and "Plausibility Illusion" which is the sense of reality of what is happening even when knowing it is not real (Slater, 2009).

Other publications and case studies of VRET for anxiety disorders have shown promising results in treatments of PTSD in returned military personnel from conflict zones and survivors of terrorist attacks (Pair et al., 2006; Rizzo et al., 2010; Rizzo et al., 2015). Another example is a VRET application for children with preoperative anxiety that replicates the hospital operating theatre to effectively reduce anxiety through gradual exposure (Eijlers et al., 2019).

Virtual reality can be developed using a variety of technologies, including 3D technology and 360-degree video. There is a lack of research that utilizes and compares both VR techniques for the same therapy and target group, especially for children. In order to investigate which VR technique is more appropriate and useful for anxiety disorder treatment, particularly selective mutism in children, this project aims to address and initiate this by developing a VRET prototype based on 360° video.

Design

Together with therapists and researchers, a concept for the VR application is designed that builds on an existing treatment protocol called "Praten op school, een kwestie van doen" (translation: “Talking at school, a matter of doing”), which is a behavioral therapy treatment provided by qualified therapists (Braet & Bögels, 2020). From this protocol, we have taken three scenarios where the degree of difficulty increases with each scenario and implemented detailed interactive 360° videos experiences using an in-house developed composition environment, as illustrated in Figure 15 - Figure 17. The resulting web-based experience is fully immersive, interactive and can be played on low-end but easily available devices, such as smartphones in VR headset enclosures. Interaction with the experience takes place through the recognition of nodding gestures and the detection of simple sounds produced by the player. An external web interface allows live intervention by therapists in case these detections fail.

Results

The prototype was evaluated among professional therapists and researchers with knowledge and experience on selective mutism and its treatment. A ”usability test” was conducted based on a qualitative review where therapists provide feedback based on observations, open-ended questions, and a survey. The results indicate that the VRET application can be of added value to regular treatments but only under the supervision of a therapist. Specific contributions of this application were identified as being: (1) a patient can be exposed to realistic settings that are not available during regular treatments; (2) a patient can practice more frequently than would be possible with regular treatments; and (3) a patient can practice just prior to an anxious situation than would be possible with regular treatment thereby potentially increasing treatment retention. Finally; valuable input was obtained that will be utilized as a basis for the development of other realistic settings.

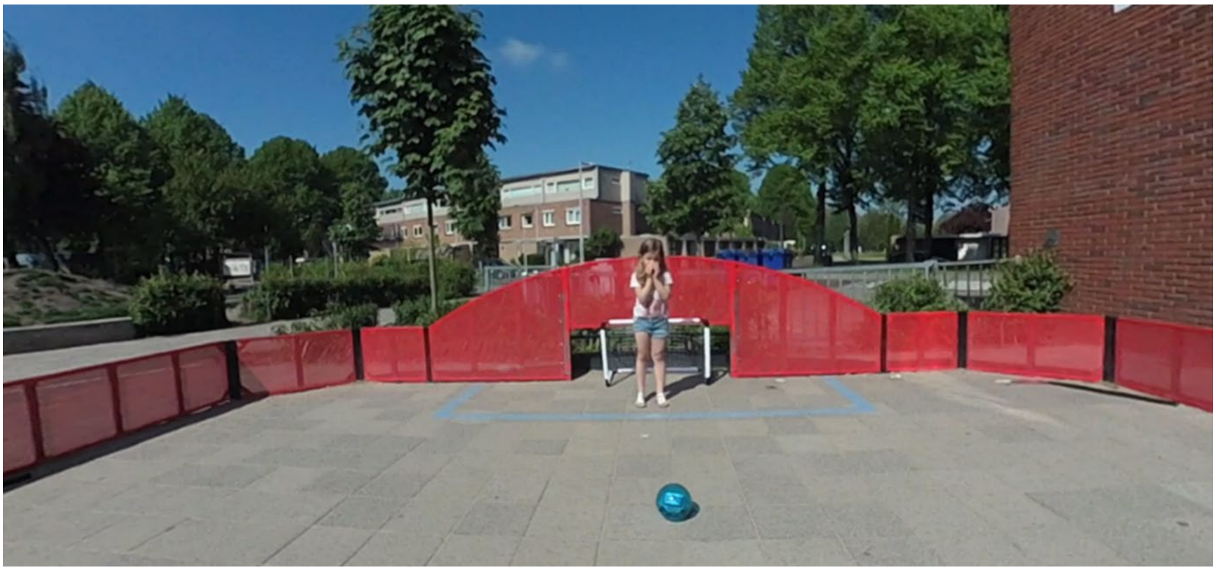


Figure 15. Schoolyard scenario (first degree of difficulty): the player is invited to participate in a game of "blow soccer". The objective is to make the player produce blowing sounds, a first step towards talking.

Figure 16. School corridor scenario (second degree of difficulty): the player is invited to repeat the sounds of animals, then to name the animals in the pictures.

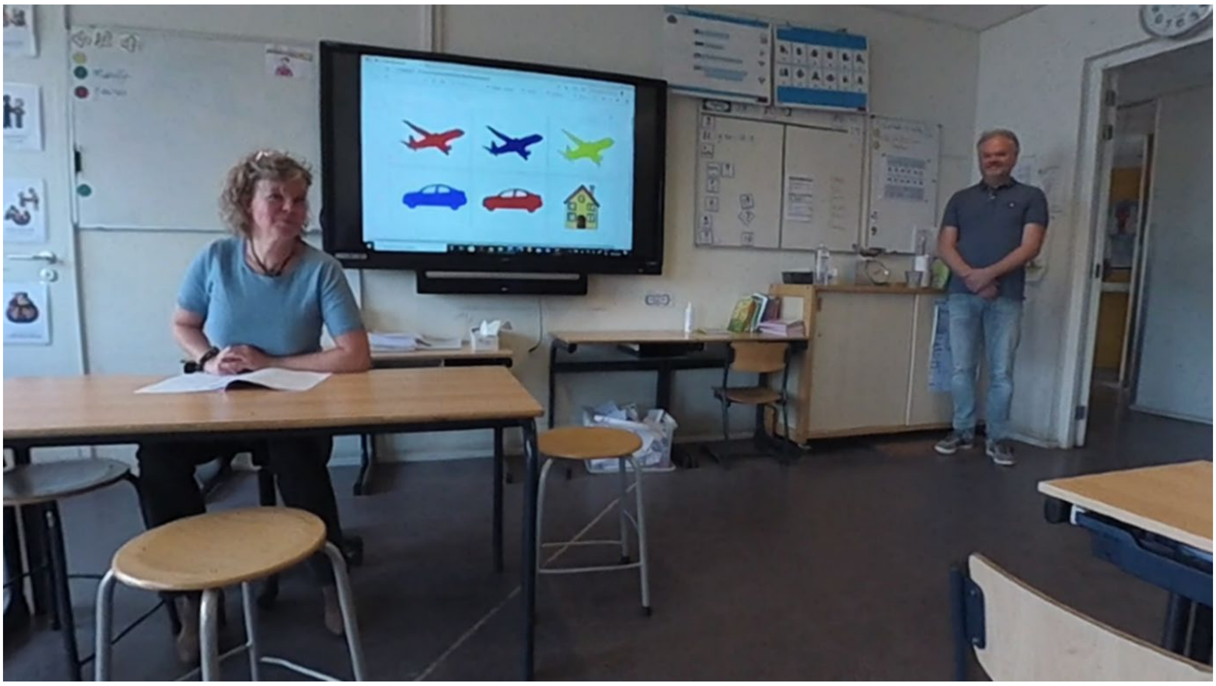


Figure 17. School classroom scenario (third degree of difficulty): the player is invited to answer simple questions and hold a simple conversation with a teacher while other people enter the room.

Conclusion

We developed a prototype of a fully immersive, interactive Virtual Reality Exposure Therapy (VRET) application, based on 360° degree videos, to augment the treatment of young children with the anxiety disorder "selective mutism". Professional psychologists and therapists participated in the design of the application and its evaluation. The results indicate that the psychologists and therapists believe in its added value to the current regular treatments provided the application is used under supervision. Conclusions as to whether the application contributes positively to the treatment of selective mutism can only be drawn in when applied in practice, which is currently under consideration. The prototype also serves as a basis for follow-up projects to treat other behavioural disorders.

References

Abramowitz, J. S., Deacon, B. J., & Whiteside, S. P. H. (2010). *Exposure Therapy for Anxiety: Principles and Practice* 5–7.

American Psychiatric Association & American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders: DSM-5, 5th ed., bll xliv, 947 p. American Psychiatric Association Arlington, VA.

Anderson, P. L., Price, M., Edwards, S. M., Obasaju, M. A., Schmertz, S. K., Zimand, E., & Calamaras, M. R. (2013). Virtual reality exposure therapy for social anxiety disorder: a randomized controlled trial. Journal of consulting and clinical psychology, 81(5), 751. https://doi.org/10.1037/a0033559

Braet, C., & Bögels, S. M. (Eds.). (2014). Protocollaire behandelingen voor kinderen en adolescenten met psychische klachten. Amsterdam: Boom. ISBN 978 90 6105 016 8

Bouchard, S., Dumoulin, S., Robillard, G., Guitard, T., Klinger, E., Forget, H., ... & Roucaut, F. X. (2017). Virtual reality compared with in vivo exposure in the treatment of social anxiety disorder: a three-arm randomised controlled trial. The British Journal of Psychiatry, 210(4), 276-283. https://doi.org/10.1192/bjp.bp.116.184234

Carbone, D., Schmidt, L. A., Cunningham, C. C., McHolm, A. E., Edison, S., Pierre, J. S., & Boyle, M. H. (2010). Behavioral and socio-emotional functioning in children with selective mutism: A comparison with anxious and typically developing children across multiple informants. Journal of abnormal child psychology, 38(8), 1057-1067. https://doi.org/10.1007/s10802-010-9425-y.

Eijlers, R., Dierckx, B., Staals, L. M., Berghmans, J. M., van der Schroeff, M. P., Strabbing, E. M., ... & Utens, E. M. (2019). Virtual reality exposure before elective day care surgery to reduce anxiety and pain in children: A randomised controlled trial. European journal of anaesthesiology, 36(10), 728. https://doi.org/10.1097/EJA.0000000000001059

Emmelkamp, P. M., Meyerbröker, K., & Morina, N. (2020). Virtual reality therapy in social anxiety disorder. Current psychiatry reports, 22(7). https://doi.org/10.1007/s11920-020-01156-1

Güldner, M., Wippo, E., Teselar, M., & Erkelens, P. (2010). Evaluatie van een behandelprotocol voor selectief mutisme. Kind & Adolescent Praktijk, 9(4), 160-166. https://doi.org/10.1007/s12454-010-0045-z.

Kampmann, I. L., Emmelkamp, P. M., Hartanto, D., Brinkman, W. P., Zijlstra, B. J., & Morina, N. (2016). Exposure to virtual social interactions in the treatment of social anxiety disorder: A randomized controlled trial. Behaviour research and therapy, 77, 147-156. https://doi.org/10.1016/j.brat.2015.12.016.

Pair, J., Allen, B., Dautricourt, M., Treskunov, A., Liewer, M., Graap, K., & Reger, G. (2006, March). A virtual reality exposure therapy application for Iraq war post traumatic stress disorder. In IEEE Virtual Reality Conference (VR 2006) (pp. 67-72). IEEE https://doi.org/10.1109/VR.2006.23.

Pallavicini, F., Cipresso, P., Raspelli, S., Grassi, A., Serino, S., Vigna, C., ... & Riva, G. (2013). Is virtual reality always an effective stressors for exposure treatments? Some insights from a controlled trial. BMC psychiatry, 13(1), 1-10. https://doi.org/10.1186/1471-244X-13-52.

Parsons, T. D., & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. Journal of behavior therapy and experimental psychiatry, 39(3), 250-261. https://doi.org/10.1016/j.jbtep.2007.07.007.

Powers, M. B., & Emmelkamp, P. M. (2008). Virtual reality exposure therapy for anxiety disorders: A meta-analysis. Journal of anxiety disorders, 22(3), 561-569. https://doi.org/10.1016/j.janxdis.2007.04.006.

Powers, M. B., Levin-Coon, A., Miller, W., Caven, A., MacClements, J., Oh, J., ... & Smits, J. A. J. (2018). A Randomized Controlled Trial of Animated Versus Live Action Virtual Reality

Therapy for Anxiety & Pain in a Level I Trauma Center. Stockholm University, Clinical psychology.

Rizzo, A., Cukor, J., Gerardi, M., Alley, S., Reist, C., Roy, M., ... & Difede, J. (2015). Virtual reality exposure for PTSD due to military combat and terrorist attacks. Journal of Contemporary Psychotherapy, 45(4), 255-264. https://doi.org/10.1007/s10879-015-9306-3.

Rizzo, A. S., Difede, J., Rothbaum, B. O., Reger, G., Spitalnick, J., Cukor, J., & Mclay, R. (2010). Development and early evaluation of the Virtual Iraq/Afghanistan exposure therapy system for combat - related PTSD. Annals of the New York Academy of Sciences, 1208(1), 114-125. https://doi.org/10.1111/j.1749-6632.2010.05755.x

Scholing, H. A., & Braet, C. (2002). Angststoornissen bij kinderen (Vol. 15). Bohn Stafleu Van Loghum.

Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1535), 3549-3557. http://www.jstor.org/stable/40538148

Wiederhold, B. K., Jang, D. P., Gevirtz, R. G., Kim, S. I., Kim, I. Y., & Wiederhold, M. D. (2002). The treatment of fear of flying: a controlled study of imaginal and virtual reality graded exposure therapy. IEEE transactions on information technology in biomedicine, 6(3), 218-223. https://doi.org/10.1109/TITB.2002.802378.

Hybrid Design using Projection Mapping AR onto 3D Printed Objects

Christoph Paul Runde

Virtual Dimension Center (VDC), Fellbach, Germany

Corresponding author: christoph.runde@vdc-fellbach.de

Keywords

Augmented reality, Projection Mapping, 3D Print, Prototyping, Clay, Hybrid Prototype

Scope

Designers like to work with physical models – but how can those be expanded with the possibilities of digital product presentation? As part of the project "*Application Center V / AR*", the Virtual Dimension Center (VDC) has now tested concepts for this.

Design processes today are characterized by a large number of methods used, which often include sketching on paper, model construction or modeling with clay. This shows the desire to work manually with the prototype during the shaping and also later in the haptic evaluation. However, these procedures are lengthy, complex and expensive, because the process includes a number of media changes. E.g. physical clay models need to be digitized (scanned); the resulting LASER scan point cloud needs to be converted into a high-quality surface of good geographic and parametric continuity.

Therefore, first companies are already trying to alter traditional design processes more or less radically. Bugatti has even claimed to have completely avoided clay in the development of its latest models [Ewing, Glon] and justified this primarily with massive time and cost savings.

Hybrid design: ideas, concepts, issues, developments

Hybrid design, i.e. the combination of physical and digital design techniques, could be a methodological bridge between proven physical and new digital design approaches. The VDC has already published first concepts in the project report "Application Center V / AR" the concept paper "Narrative Applications. Report # 5: Hybrid Design Journey". The focus there was on techniques of augmented reality, implemented by projection onto physical objects, such as models from the 3D printer.

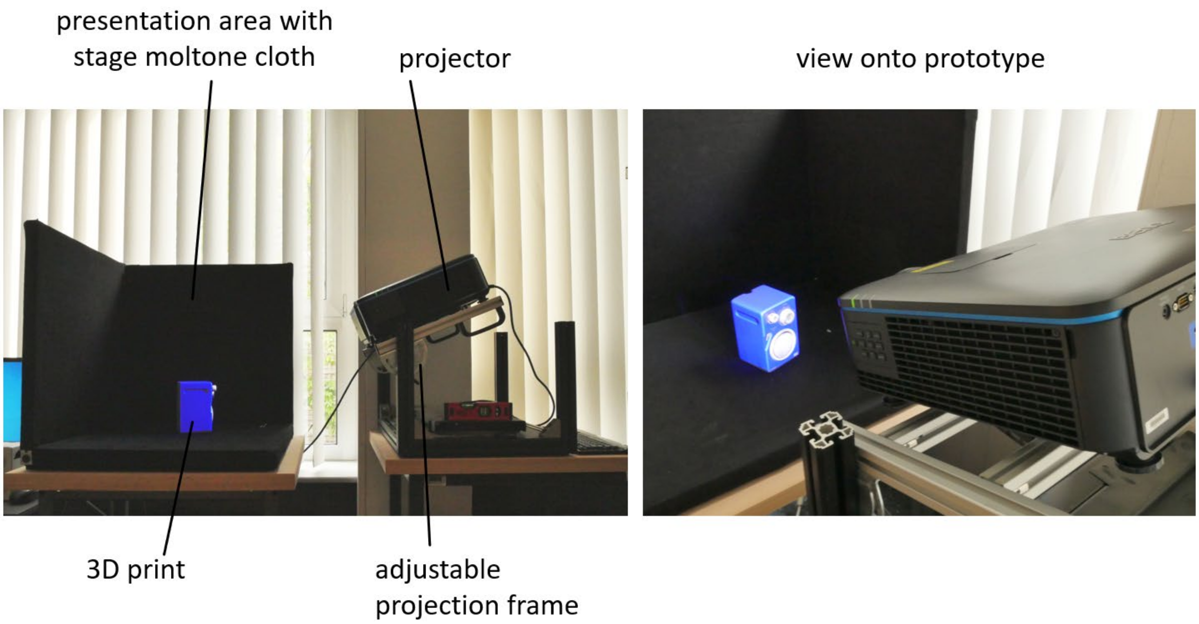


Figure 18. Demo setup for projection mapping AR hybrid prototypes.

A number of open issues arose from this aforementioned project report, namely:

a. **3D model generation and preparation:** Which VR modeling tools are applicable? How can the generated 3D models be further processed?

The range of immersive 3D modeling/sketching tools has increased over the past 3 years, so that there is now a small range of solutions (Google Blocks, Google Tiltbrush, Gravity Sketch, MasterpieceVR, Oculus Medium, ...) to choose from. 3D sketching tools have to create 3D models that can then be processed further efficiently, e. g. for our use cases of 3D rendering and 3D printing. The 3D rendering has lower requirements, since physical laws (no infinitely thin surfaces, no open objects, no detached surfaces, ...) do not have to apply here. The situation is different with 3D printing, since it relies on solid bodies. All the sketching solutions considered can export 3D data, whereby Google Tiltbrush being primarily a 2D sketcher (probably in 3D space, but ultimately you create spatially located surfaces, not solids) should be treated with caution. The available 3D export formats .obj., .stl and .fbx are also very widespread and are supported by all common 3D modeling, design tools and 3D post-processing solutions. Solids are generally required for 3D printing, i.e. elements for which a volume can be calculated. An extreme level of detail is not required neither for rendering nor for 3D printing, as we reach the limits of the print resolution at some point. Especially when tessellating complex, parametric models, huge models can result, which must therefore be reduced. The VDC looked at numerous tools for digital 3D model preparation. The focus was on the functions for preparing 3D models for 3D printing. The following tools showed a good job: Autodesk Meshmixer, Blender3D, FreeCAD, Meshlab and Ultimaker Cura. Using the stated sketching and preparation tools, the process chain from VR modeling to 3D printing and high-end rendering can therefore be closed.

b. Light control and single-channel versus multi-channel projection

Surfaces that are illuminated by the projector at a large / very large angle will appear too dark when viewed from the side (i. e. not from the direction of the projector). Compensating lighting concepts for the 3D scene need to be created here. Is only one projector sufficient or should the 3D printing be illuminated from several sides? What are the good angles of illumination for a viewer who is not at the position of the projector? A 3D print as a physical object cannot be illuminated from all sides at the same time by one projector (without the use of mirrors). What are the limits and when should several projectors be considered?

Illuminated sides: By rotating the 3D print around its vertical axis and lifting and tilting the projector, it is entirely possible to illuminate three sides at the same time (see Figure 18). This is the simplest setup.

Distribution of focus: A physical, spatial object means different distances between the projector and the projection surfaces. Since the projector is focused (brought into focus) at a certain distance, this can be problematic. Modern projectors already show a very good elasticity (Scheimpflug's rule applies to a larger distance range), which is even exceeded by short-distance or ultra-short-distance projectors.

Resolution distribution: Since the three sides are generally irradiated at different angles, the pixel resolution per area can also be very different. The surfaces that are illuminated at a large angle experience a very coarse resolution. In addition, due to the oblique illumination, the pixels can be distorted in a trapezoidal shape, so that no clean edge finish can be seen.

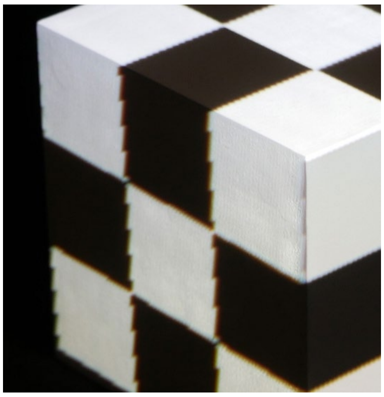


Figure 19. Pixel distortion due to angled front projection.

If the sides, in combination with the frontal view, are very important for visual assessment, the use of several projectors must therefore be considered. Even if the object is to be illuminated from more than three sides at the same time - e. g. for group meetings with the 3D printing in the middle, several projectors must be used. The use of several projectors can mean that overlapping lighting areas have to be compensated by using edge blending.

Light Distribution: Since the three sides are generally irradiated at different angles, the incident light is distributed over the surfaces with different intensities: the surfaces that tend to point more towards the projector appear bright; the areas that tend to point away from the projector (but are not yet on the back) appear darker. As part of the work described here, two lighting concepts were tried out that are intended to help compensate for the problem outlined above. On the one hand, virtual light sources were implemented in a fixed location with respect to the virtual camera.

On the other hand, virtual light sources were implemented in a fixed position in relation to the coordinate system of the virtual 3D object. In both cases, the intensity of the side lights could be controlled independently of the front light.

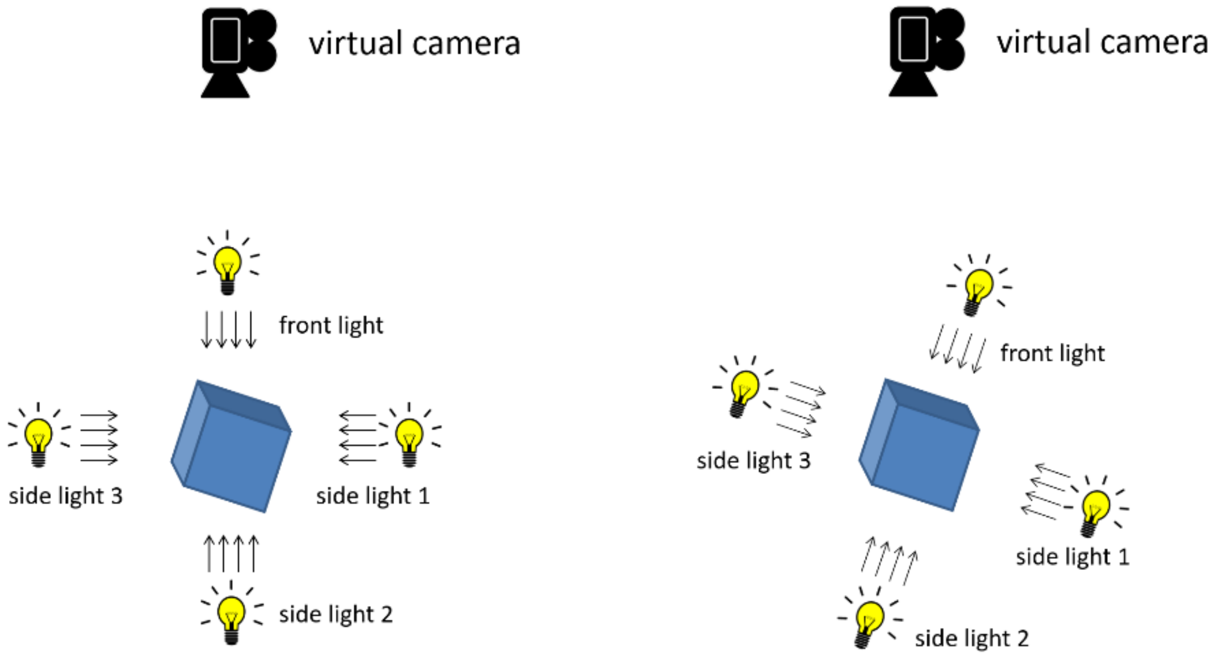


Figure 20. Two virtual illumination concepts.

The physically correct concept is basically the former, since the projector is the central moment here: from its point of view, the recording is made by the virtual camera and ultimately it is decisive how the light sources and the surfaces are directed towards it are. However, if the 3D scene also contains objects that are clearly at right angles to each other, it may look better if the object and its surface orientations are decisive for the positioning of the light sources. The figures below show the practical result of the experiment.

On the right, we can see physical cubes with projected patterns on them. In the case of the lower right-hand cubes, it was possible to control the brightness of the sides independently of the front, so that they appear approximately equally bright. How the brightness distribution should look in practice depends, of course, on the application (e.g. the conception of the 3D scene).

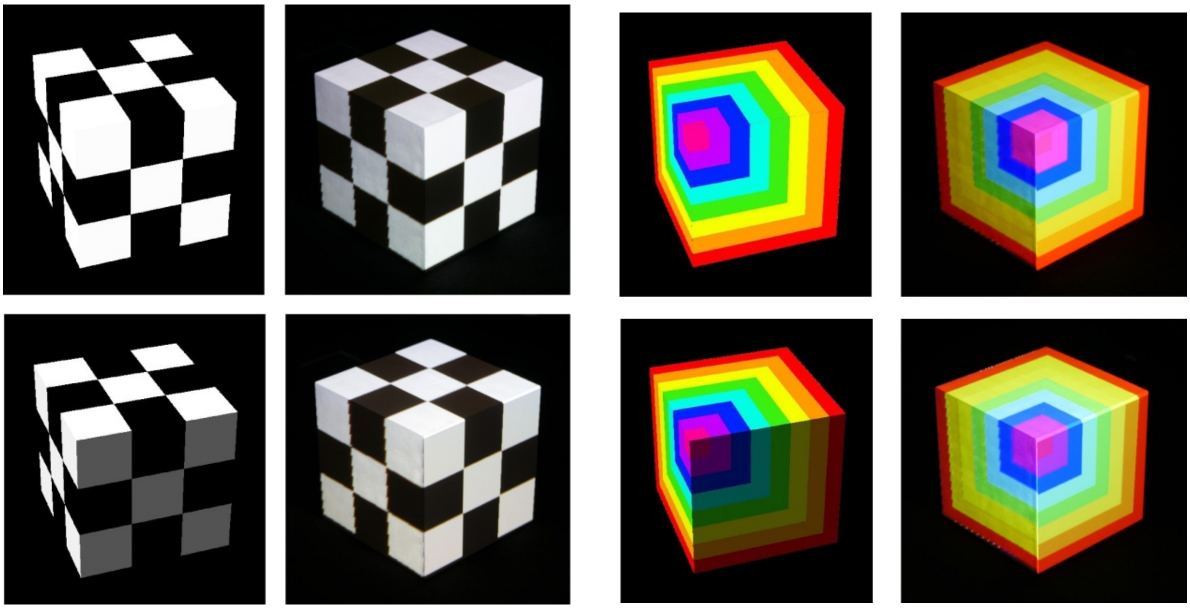


Figure 21. Comparison of black-white and colored contrast without light compensation (top row: rendering on the left and photo of the 3D print on the right) versus with light compensation (bottom row: rendering on the left and photo of the 3D print on the right)

c. Two perspectives rendering and stereo vision

Elements that are spatially behind the projection plane (i. e. the surface of the 3D print; e. g. behind the glass front) are shown incorrectly in perspective when viewed non-frontally (viewer is far away from the position of the projector lens). How can this be corrected? How useful, good and feasible is 3D stereo vision and when?

Two perspectives rendering: If the geometry of the 3D print corresponds to the geometry of the virtual object used for the projection (no interiors behind the surface, not only virtually existing attachments without a physical equivalent), the digital 3D representation can easily and easily be used as the projection content. The situation is different if there are digital 3D elements that should be inside the 3D print, e. g. behind glass windows or if there are digital 3D elements that have no physical equivalent and that protrude from the geometry of the 3D printing, e.g. attachments that do not yet physically exist, drawers that slide out, etc. Virtual elements that are spatially in front of or behind the projection plane (i.e. the surface of the 3D printing; e.g. behind a virtual pane of glass) become incorrect in perspective when viewed non-frontally (viewer is therefore far away from the position of the projector lens) when rendered as simply as described above.

Therefore, the two angles of rotation (3D print towards projector: *alpha* and 3D print towards viewer: *beta*, see Figure 22) and the two tilt angles (3D print towards projector: *gamma* and 3D print towards viewer: *rho*, see Figure 22) must each be taken into account.

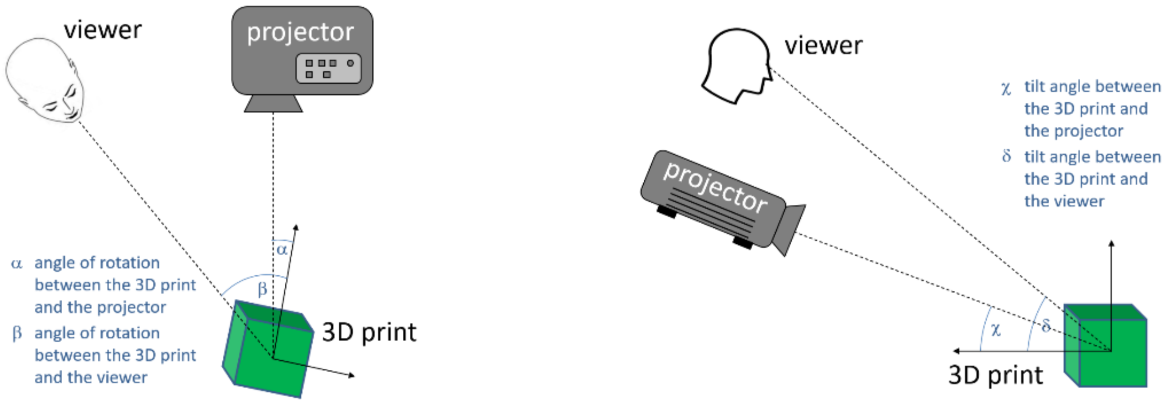


Figure 22. Angles between 3D print, projector and viewer.

For testing purposes, a small 3D scene consisting of a cube with an edge length of 10 cm, a window cutout, three LEGO bricks and a LEGO character inside was digitally designed and modeled (see Figure 23-Figure 26). If we now look at this box from an oblique perspective (i.e. increase the angle), there must be changes in perspective for the viewer - regardless of where the projector is (remains constant) - as can be seen in Figure 23. The outside view of the box (see Figure 24), on the other hand, also remains constant at constant *alpha*. The challenge is to create a rendering that combines the perspective of the projector (outside view of the box) with the perspective of the observer (side view of the inside of the box). This was technically implemented using a rendering with two layers, with the outer shell of the cube forming the front layer and the box interior being the rear layer from the viewer perspective. The interior rendering must then be distorted linearly so that it fits into the projected image. The interface between both layers is the frame, which must be the same for both (window cutout, pane surround, etc.). Figure 25 shows photos of the physical box with composite renderings from two layers, projected onto the physical cube. Here, the angle was increased step by step, at the same time the photographer adjusted his position so that this angle corresponded to reality. The result looks consistent. The final evaluation is made by recreating the scene and taking corresponding photographs.

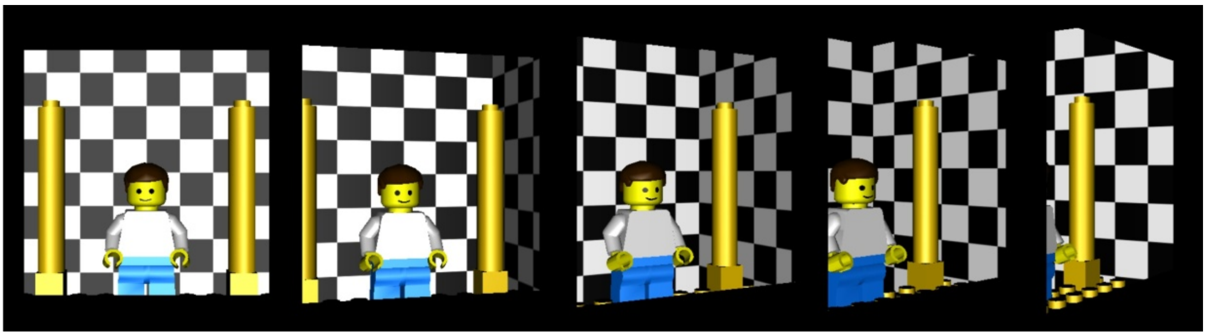


Figure 23. Interior scene: increasing the angle of rotation beta between the 3D print and the viewer.

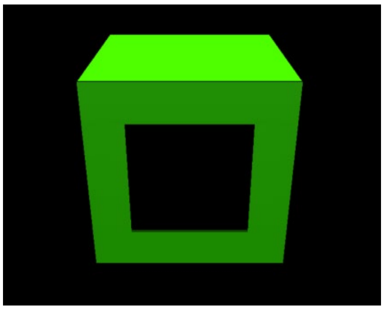


Figure 24. Exterior scene: remains constant with a constant relationship between the 3D print and the projector alpha

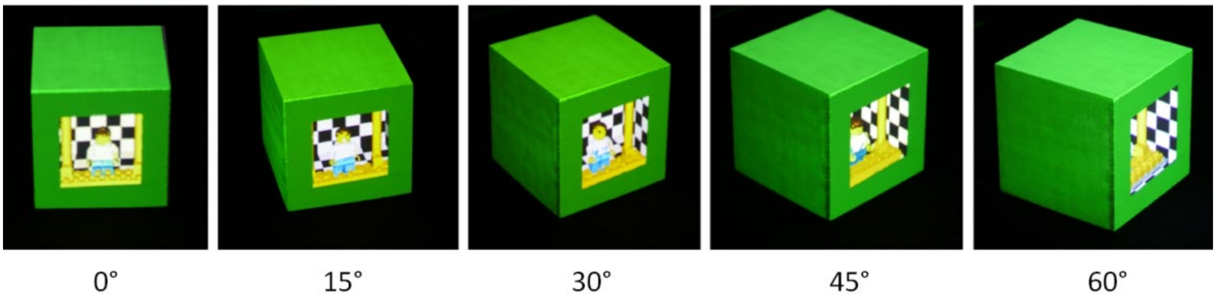


Figure 25. Photos of the physical cube with projected, composite renderings from two planes with a variable angle of rotation beta

Figure 26 shows the closed cube without (left) and with (middle) projection as well as the exactly corresponding physical replica (right). The photo camera remained unchanged on the tripod, the cubes were merely exchanged in the same position. The evaluation was thus completely successful.

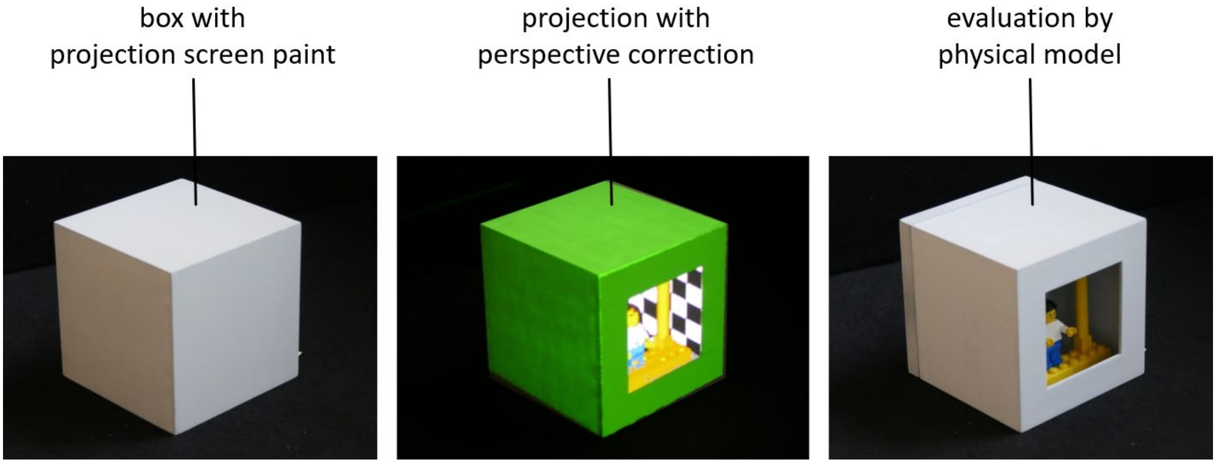


Figure 26. Evaluation of the 2-perspective rendering using a physical replica

Stereo vision: How useful, good and feasible is 3D stereo vision for which purpose in the case of hybrid prototypes? If the geometry of the 3D print totally corresponds to the geometry of the virtual object used for the projection (no interiors behind the surface, no additions that are only virtually existing without a physical equivalent), the viewer's stereo perspective results automatically from his or her natural view of the physical 3D image. No digitally generated stereoscopy is required for this setting. The situation is different if there are digital 3D elements that should be inside the 3D print, e. g. behind glass panes or if there are digital 3D elements that have no physical equivalent and that protrude from the geometry of the 3D printing, e. g. physically not yet existing extensions, drawers that slide out, etc. Since these described 3D elements have no physical representation but are projected onto the surface of the 3D printing, they should be perceived in front of or behind the projection plane (= surface of the 3D printing). Stereoscopic techniques are used for this (see Figure 27).

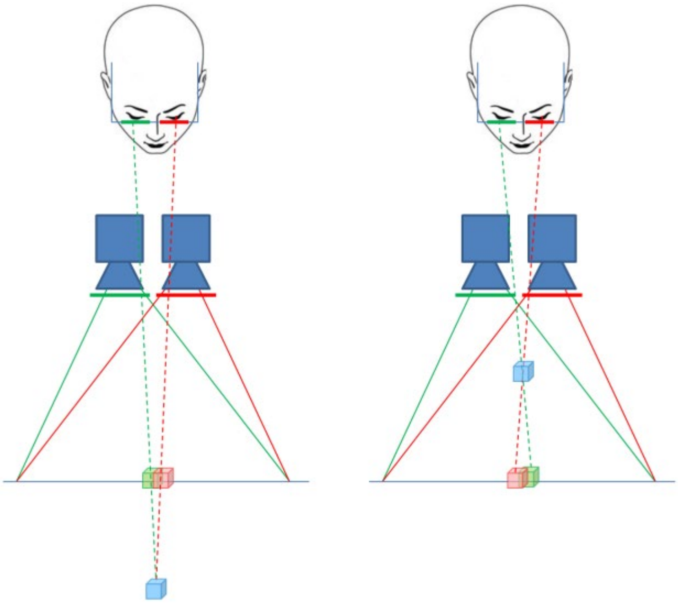


Figure 27. Use of stereoscopic techniques if you want to make a 3D object (blue cube) appear in front of or behind the projection surface (blue line).

The prerequisites for a sensible use of stereoscopy are thus exactly identical to the conditions that require a 2-perspective rendering! For this purpose, two perspectives of the partial scene (shown in red and green in Figure 27) must be generated, which correspond to the views from the right and left eye. These are simultaneously projected onto the 3D print and separated from one another using appropriate stereoscopic filter techniques (active shutter, polarization filter, INFITEC, etc.).

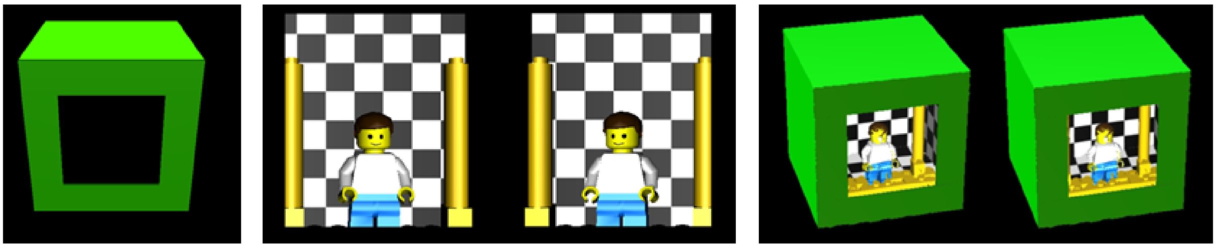


Figure 28. Exterior view; left eye view, right eye view; side-by-side stereo image from outside and inside. Left the view for the left eye, right the view for the right eye. Projection was done in active stereo.

For the viewer, the stereoscopic 3D objects appear at the blue positions. Stereoscopy is therefore only useful and necessary if there are not physically visible interiors or non-physically existing extensions that are to be digitally displayed (projected). All of the rest of the outside view of 3D printing is unaffected by stereoscopic considerations.

d. Projection medium

There are coatings for projection surfaces with different properties, especially brightness and degree of dispersion (gain). Which coating is optimal for the application at hand?

Nowadays, high-performance coatings are used for professional projection surfaces. One of the important properties of projection surfaces is their reflectivity, which is described by the luminance factor. As a comparison, barium sulfate, $BaSO_4$, is used as the white standard. The luminance factor is measured with an almost vertical projection in the middle of the screen. The luminance factor is the luminance of a screen sample divided by the luminance of a white standard. The luminance factor gain is greater than 1 on the screen normal for a type D screen compared to the white standard. This value changes depending on the deviation from the screen normal. In order to achieve better black in a bright room, screens with a gain factor of 0.6 are increasingly being used. These black screens use the same principle as tube televisions or LC displays. In order to achieve the necessary contrast, projectors with more than 3000 ANSI lumens should then be used here. In the present case, we are illuminating a relatively small object (a 3D print) at close range with a powerful projector. Thus, we are dealing with a quite high luminance. This means that we can use very dark coatings: the challenge is to get a good black level; We can easily achieve a good white value through the projector's performance itself.

High performance coatings are manufactured e. g. by the Canadian company Goo Systems. Products with different gain values are sold, from 1.0 (reference white) to 0.4 (dark, "Ultra Max Contrast"). As part of our investigations, the coatings "High Contrast" (Gain 0.85) and "Ultra Max Contrast" (Gain 0.4) were used. In order to reduce further the brightness of this coating, the tinting concentrate "Mixol 1 Black" was used additionally.

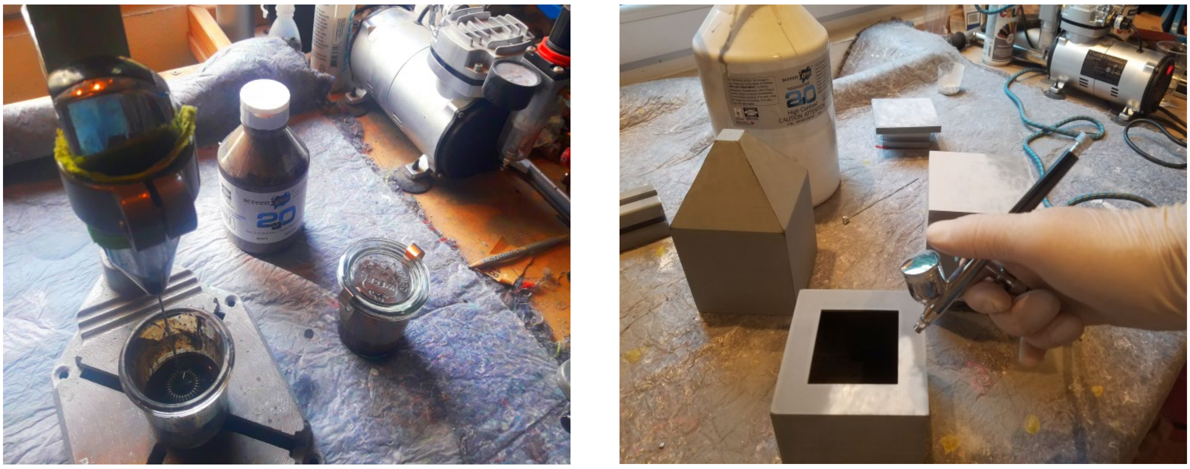


Figure 29. Mixing small amounts of the gray tones with a milk frother.

Usually, large areas such as wall surfaces or panes are provided with such coatings; brushes and rollers are used for this. Our tests for 3D prints have shown unsatisfactory results when applied with a brush. An airbrush system was subsequently used. However, the viscosity of the coating is designed for airbrush systems with a nozzle cross-section of 1 - 2 mm (large airbrush systems for large areas). Here, however, we are dealing more with a model scale, for which a small airbrush system with nozzle cross-sections of 0.1 - 0.5 mm is to be used. The use of airbrush systems suitable for model making with the unchanged coating therefore quickly clogged the nozzles. This was remedied by a flux (airbrush medium), which in tests proved to be more efficient than nitro thinner. With these specified components

- Screen Goo 2.0 High Contrast Gain 0.85
- Screen Goo 2.0 Ultra Max Contrast Theme Park Gain 0.4
- Black tinting concentrate
- Airbrush medium

A total of eight shades of gray (Figure 30) was carefully mixed (Figure 29) and eight primed standard cubes (10 x 10 x 10 cm) were coated (Figure 30) afterwards. Then these cubes were lit with a black and white diamond pattern and photographed (see Figure 30). Both black and white squares fell on each of the physical dice.

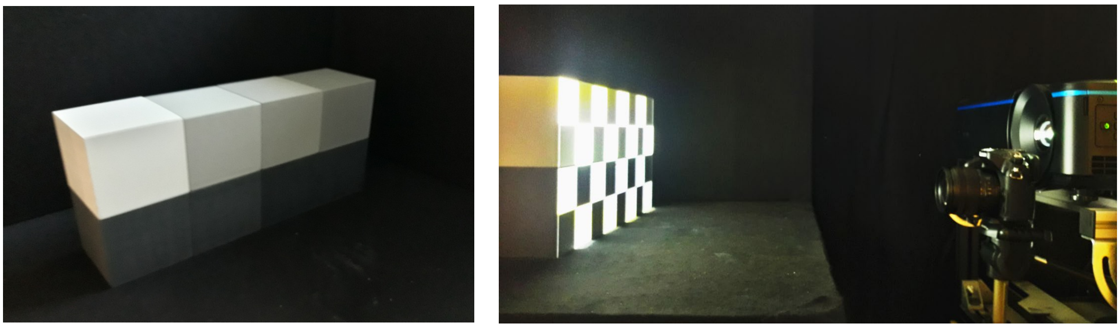


Figure 30. Eight cubes in different shades of gray; on-projection and simultaneous photo taking.

Eleven photographs were taken at different brightness levels (0%, 10%, 20%, ..., 100%) of the projector, but with identical camera settings (aperture: 22; shutter speed: 8). Core areas of each black area and each white area of the photos were cut out and their histograms were analyzed. The average brightness values given in the histograms are the measurement results that are related to each other.

Figure 31 shows the overall comparison with the strongest reasonable projector brightness (50%). Relatively good contrast ratios of 24-27, with brightness differences of 144-154 being achieved with cubes four, five and six. The black values are a good 7, the white values 169-180. If you look at the gray value table, you end up with gray values mouse gray (RGB 100-107-099), graphite gray (RBG 071-074-081) and slate gray (RGB 067-071-080). These are even visibly darker than the standard color Screen Goo 2.0 Ultra Max Contrast Theme Park Gain 0.4. The limit is presumably set by the projector due to its maximum achievable contrast: if our projector could also be used sensibly beyond 50%, even darker elements could well be used.

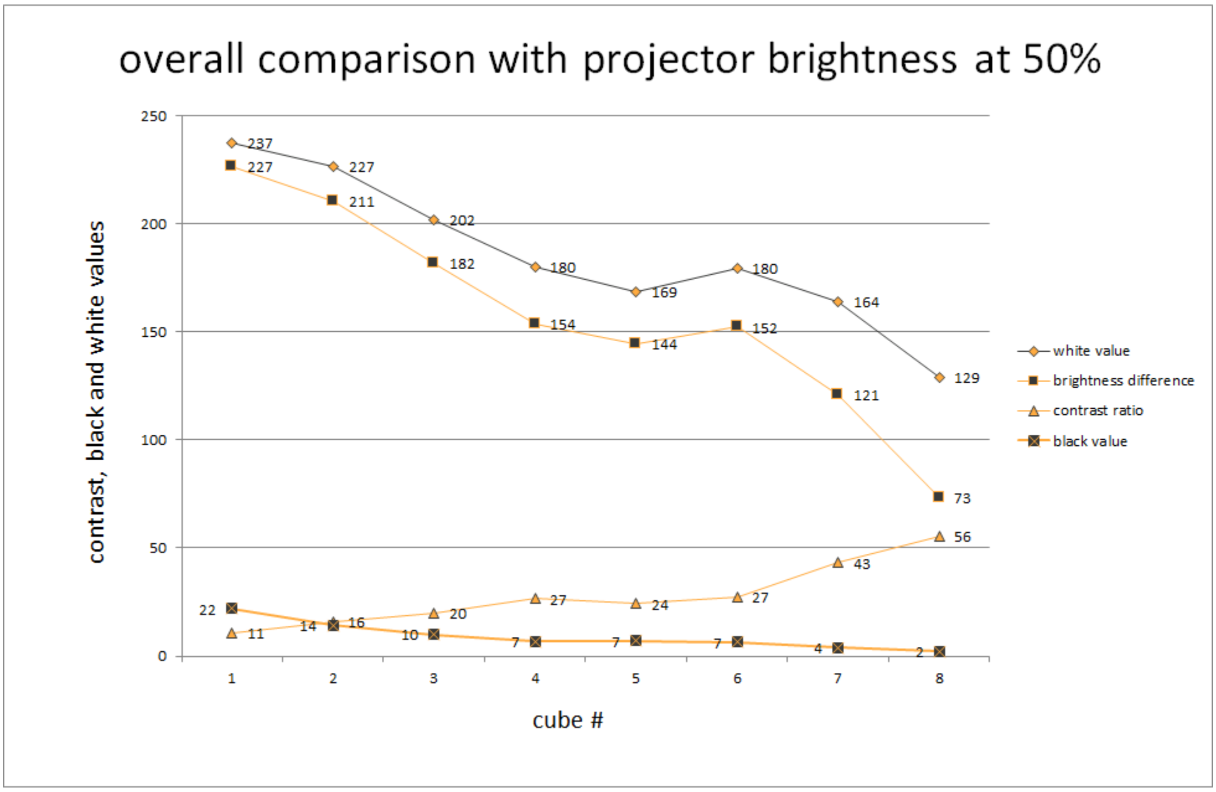


Figure 31. Overall comparison and selection of the optimum coating color.

e. Making 3D prints interactive

For user interface developments, direct interaction with the 3D printed object would be useful. But how can a good direct interaction with the physical 3D model, i.e. 3D printing, be realized? So how does the interactive 3D print model work?

Method 1: Optical detection of fingers and hands: There are software frameworks that can recognize hands, fingers and gestures via normal RGB cameras or via RGB-D (depth) cameras. There are also ready-made camera software integrations and even software camera-projector integrations. We considered following solutions: Mano Motion (https://www.manomotion.com), LeapMotion (https://www.leapmotion.com), and Sony Xperia-Touch (https://developer.sony.com/develop/xperia-touch/). The entire integration of the projection unit, camera and gesture recognition from Sony basically offers some interesting options, but in practice it turned out to be unsuitable for the intended purpose, because it requires a flat projection surface. A camera-based gesture recognition, on the other hand, would work in any case, but would be associated with a high and product-specific amount of work. None of the solutions discussed was completely convincing.

Method 2: Installation of sensors in the 3D printed object: Real, physical sensors can also be built into 3D printed objects. Professional 3D printers even offer the option of including sensors by briefly interrupting the printing process at a suitable time. Suitable sensors can be rotary encoder, touch display, or capacitive touch sensors. All of these sensor examples could be operated by an Arduino development board. Arduino is a physical computing platform made up of software and hardware. Both components are open source. The hardware consists of a simple I / O board with a microcontroller and analog and digital inputs and outputs. The development environment is intended to facilitate access to programming and microcontrollers even for those who are less technically experienced. The programming itself takes place in a programming language similar to C or C ++, whereby technical details such as header files are largely hidden from the user and extensive libraries and examples simplify programming. Arduino can be used to control standalone interactive objects or to interact with software applications on computers.

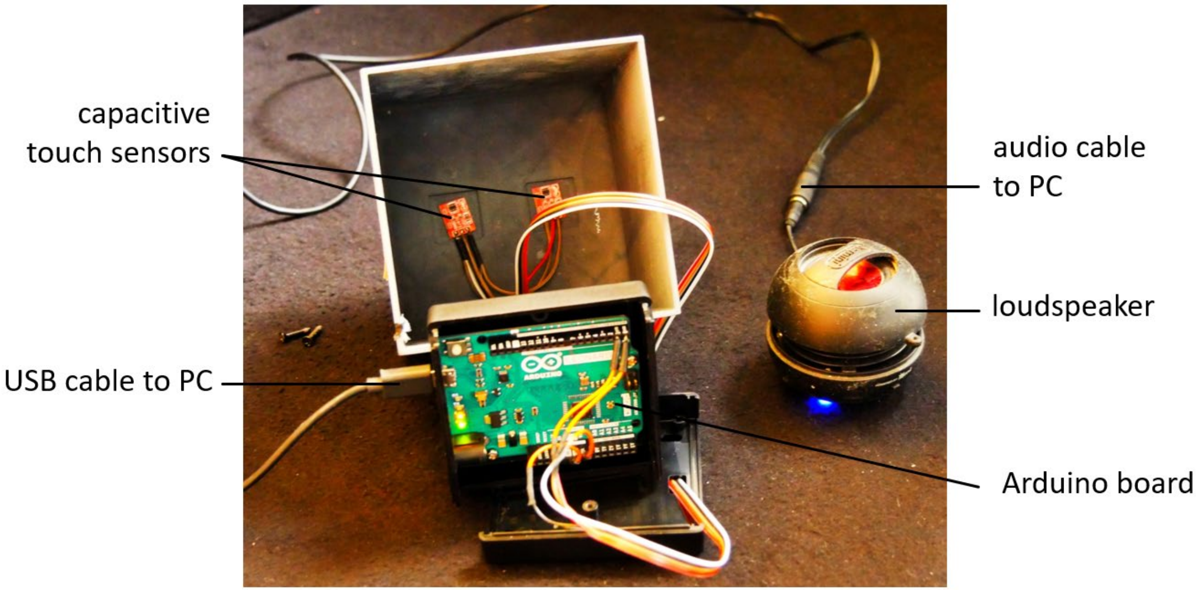


Figure 32. Physical experimental setup to test the touch sensors in a 3D printed object.

Evaluation and Case Studies

Evaluation: At the Virtual Dimension Center, a evaluation setup was created made up of a 3D printed object, the aforementioned touch sensors, and with an Arduino board. The capacitive sensor (dimensions: 15 x 11mm) is suitable for switch input without wear or mechanical actuation. The module is simply connected to a power supply and emits a high level (i.e. a digital output) via the I / O connection when fingers approaching. Due to the capacitive functionality, it can also be installed behind objects such as a PLA (plastic) layer. Preliminary tests at the VDC showed that this touch sensor can be used behind a PLA layer up to 4 mm thick. This is where it works most precisely, as the one behind very thin layer often triggers very early (the sensor is thus capacitively activated, although there is no contact with the surface. This can be irritating). Another hollow cube was printed into which two touch sensors were glued (see Figure 32). The Arduino board and a battery-operated loudspeaker were also housed in the cube. The connection to a PC was made via a USB and an audio cable. Figure 32 shows the inside of the experimental setup. A simple digital 3D scene was modeled, consisting of a cube that contains a (virtual) display field and two virtual pushbuttons (see Figure 33). Since the buttons do not react haptically, the user only feels the touch of the cube surface when operating them. In order to still implement a feedback loop for user interaction, two mechanisms were therefore built in:

- when the touch sensor is triggered, the buttons are pressed into the housing in an animated manner. This is visible; so, there is visual feedback.

- clicking noises are played both when the button is pressed and released and output via the loudspeaker in the cube. Since humans can locate sounds, there is thus consistent acoustic feedback of the interaction.

The display was shown a movie texture in which the (dynamic) station search of a radio is displayed. In addition to the clicking noises, the station search is played. This starts as soon as one of the buttons is pressed. The other button changes the color of the cube.

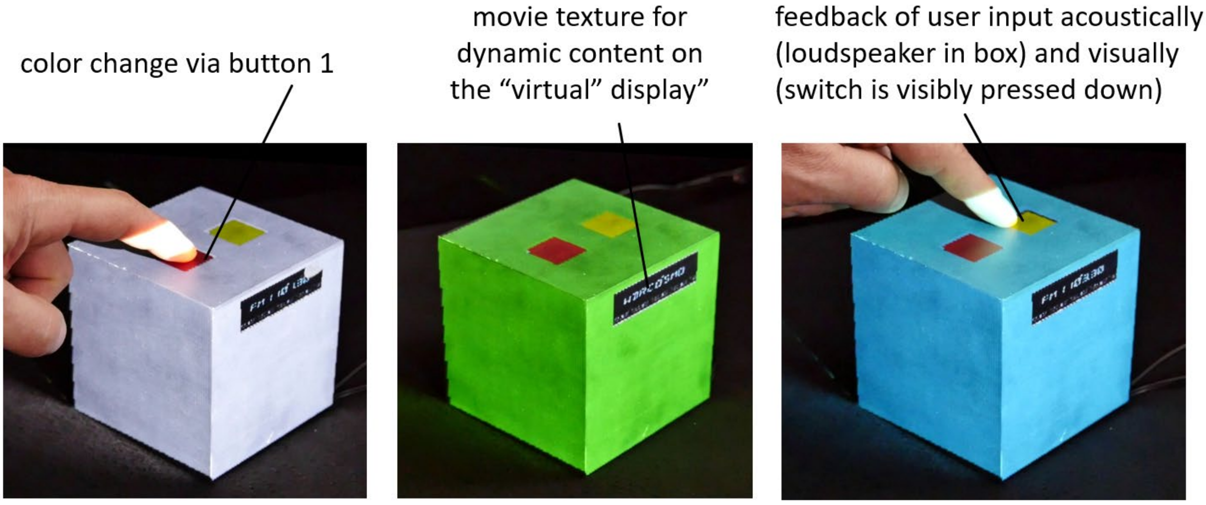


Figure 33. 3D scene for testing the touch sensors in a 3D printed object.

Conclusion on the interaction of 3D printed objects: The tests at the VDC showed that the installation of sensors in 3D printing can be done easily and inexpensively and leads to a robust overall system. Wireless solutions for both the Arduino and the speaker are feasible. It would have been interesting to simulate a touch field using a matrix of touch sensors. However, this is not possible (at least with the Debo product that was tested), as it would require touch sensors with an analog output signal (depending on the distance to the finger, for example).

Case study #1 dealt with the selection of materials for the medals for the World Athletics Championships in Stuttgart in 2019. The 3D model of the medal came as a STEP file (.stp) and could easily be 3D printed on a 1: 1 scale without any major adjustments. It was coated in RAL 7015 slate gray on the basis of Goo Screen 2.0 Ultra Max Contrast Gain 0.4. At the same time, high-end renderings were created with 3D Studio Max with specified tilt angles between the projector and the 3D printing. These high-end rendering (2D images) were then projected onto the coated 3D print. Since the object is flat, a very steep angle of incidence was chosen. The end result showed the reflections on the object on a scale of 1: 1 (see Figure 34) in an excellent quality. At the same time, one could capture part of the feel of the medal. Unfortunately, the cold haptics and the weight of the metal cannot be reproduced with the resources available.

Figure 34. Unlit and illuminated 3D printing side by side; Photograph of the final result.

Case study #2 Mercedes AVTR. This name of the pioneering concept vehicle not only stands for the intensive collaboration during the development of the show car with the AVATAR movie team, but also for ADVANCED VEHICLE TRANSFORMATION. This concept vehicle embodies the vision of Mercedes-Benz designers, engineers and trend researchers for mobility in the distant future. The holistic concept of the VISION AVTR combines the design disciplines interior, exterior and UX in a new form. The unmistakable inside-out design structure connects inside and outside to an emotional whole and was inspired by several living beings from the film AVATAR. With the stretched "One Bow" design and the organic design language, the VISION AVTR offers a visionary outlook on the design of the future. With the AVTR model, the manufacturer wants to redefine the term "Sustainable Modern Luxury" and at the same time symbolize the demand for sustainable mobility of today, tomorrow and even the future. The creative and trend-setting elements of the show car are in line with the current Mercedes-Benz brand philosophy, which aims to focus on people and at the same time sets standards for the future of mobility. Future vehicles will be developed from the inside out, which was previously done the other way around. The following display concepts were tested using this example.

- lighting concepts: control of the virtual light sources in order to achieve a satisfactorily realistic view of the irradiated 3D print
- representation of different paint colors
- retracting / extending the tailgates
- switching the lighting of the balloon tires on / off
- switching the headlights and rear lights on / off
- stereoscopic view of the interior: The active stereo method was used here, in which the viewer has to wear (active) shutter glasses. The two images for the right and left eye are projected onto the 3D print and appear as a double image of the interior without using the shutter glasses.
- sound in the vehicle (e. g. when adjusting the tailgate): this way it is made clear again when something in the vehicle is moving or being adjusted.
- perspective correction of the view into the interior: the figures show that the developed method does work. A second layer was placed over the vehicle outer skin visualization (which is identical for the right and left eye), which contains the view of the interior. Here - a special feature of this demonstrator - the views through the windshield and the side windows had to be pre-distorted separately from one another, as they lie in different projection.

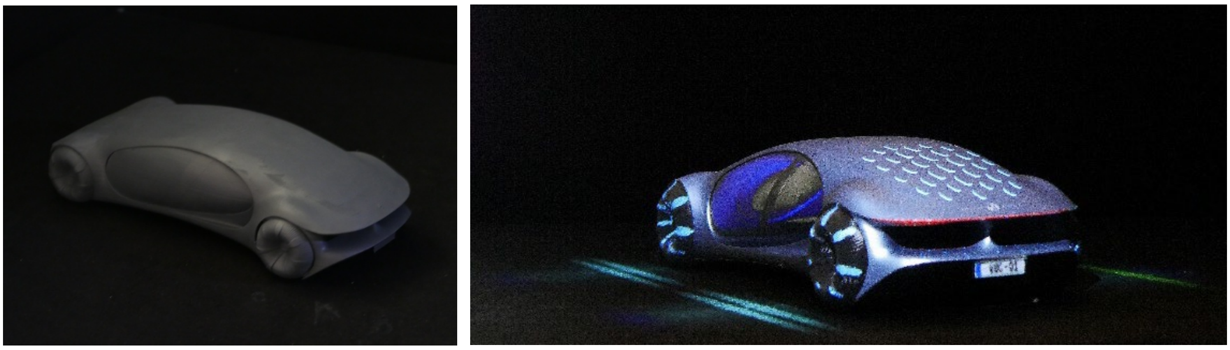


Figure 35. Use case of Mercedes AVTR.

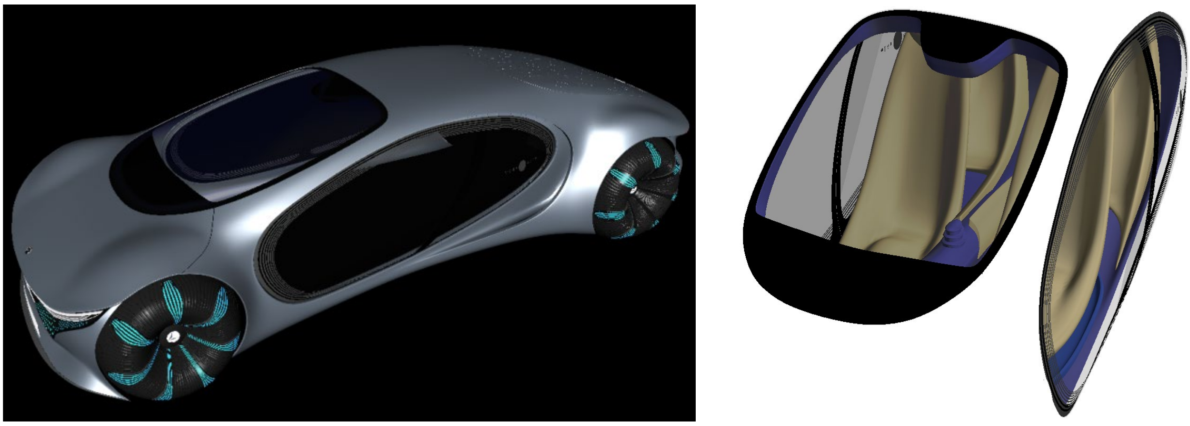


Figure 36. Layer with the outer skin of the vehicle (background layer, left) and the layer with the interior views of the vehicle (foreground layer). These two elements must be fitted separately from one another in the window openings of the background layer.

Case study #3: The Siemens WM14U940EU washing machine is one of the flagship products from BSH (Bosch Siemens Home Appliances). The avant-garde design for laundry care is a modern, minimalist concept that combines functionality and style: the blue light ring, the sloping control panel and the iSelect display improve operator comfort, while the seamlessly integrated large door with door opening leave a lasting impression at the push of a button and the high-quality chrome line. The following display concepts were tested using this example:

- lighting concepts: control of the virtual light sources in order to achieve a satisfactorily realistic view of the irradiated 3D print
- retracting / extending the detergent drawer
- animation of the laundry drum, underlay with working noises
- animation of the pressure switches (push in) and
- underlay with switching noises
- subdivision of the overall scene into three layers: foreground: detergent drawer; middle: machine body; background: drum
- perspective oblique view (off-center projection) into the laundry drum and onto the detergent drawer
- stereoscopic view into the laundry drum and on the detergent drawer
- direct control of the two buttons via touch sensors integrated in the 3D printing.

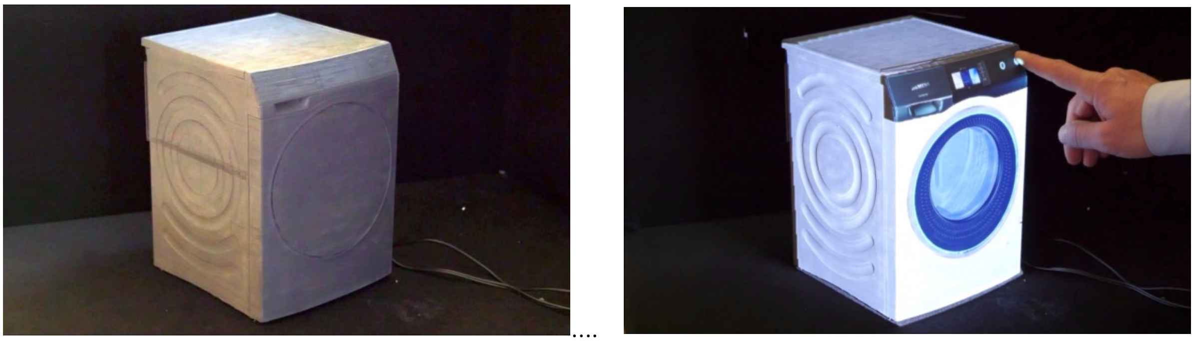


Figure 37. Use case of BSH; operating simulation of the washing machine using touch sensors built into 3D printing.

Figure 38. Scene decomposition into 3 layers, necessary for perspective correction (distortion) and stereoscopy.

Conclusion

The work presented in this paper deals with issues raised in the report Concept Paper "Narrative Applications. Report # 5: Hybrid Design Journey". The focus was to determine where the possibilities, limits and further development potential of a hybrid approach in design lie, that makes use of the opportunities of 3D printing combined with projection. This work took several months and included a number of correction loops that are not shown here. The knowledge gained from this is of course an implicit part of this report. Overall, the following evaluations can be made at the end of this work. Immersive generation of 3D models in VR sketching programs is state of the art today. These models can be further processed into 3D prints and visualization objects. However, the 3D model preparation is sometimes time-consuming if the subject of 3D printing was not considered from the start (loose surfaces, non-manifolds, no solids, ...). The simple front projection onto a 3D print is basically feasible and creates already appealing representations. Mirror and gloss effects as well as the view through glass or into 3D objects (behind the projection surface, i.e. the 3D printed surface) worked very well. The compensation of underexposed and overexposed areas of the model via the simple light control presented also worked very well. The originally defined requirements for the projection technology had to be revised. Lens shift should not be used under any circumstances: shifting an image on a plane perpendicular to the projection axis is absolutely desirable for simple 2D content (e. g. a film shown on a screen), but it works with 3D content and not vertical Projection surfaces lead to distortions that can hardly be compensated. Projector calibration: If the projector used is capable of lens shift, it should be deactivated or moved to the zero position. The exact angle of inclination of the projector must either be known or set correctly. At the VDC, this was returned to the zero position of the lens shift and the projector inclination was set using the standard cubes mentioned at the beginning, onto which a regular diamond pattern was projected. A suitable front projection can only result in the lens shift zero position and if the angle of inclination of the digital 3D model and the projector match. Short-distance projectors are generally a good choice, as they can also focus on objects at a very short distance. Wide-angle lenses are not recommended because they fan out the image. This results in relatively few pixels (picture elements), which are then actually placed on the 3D print. A normal lens would add more pixels to the 3D print here. Commercial projection screen coating can be tinted significantly darker in order to obtain excellent contrasts and good black values. The contrast ratio of the projector ultimately defines the limit. The work presented here has clarified where off-center views and stereoscopic views are useful and necessary, namely for elements that are hidden inside the 3D print and for elements that protrude from it virtually but physically are not present. The off-center views of the interior and outstanding components could be created and were meaningful in the representation. The stereoscopic views of the interior and outstanding components could be created and were meaningful in the representation. A simple VRML player was used as the rendering engine. As a technology for displaying the various visualization layers, scenes and components were rendered as different perspectives and placed as dynamic textures on surfaces, which were then appropriately distorted. Due to the technical limitations of these dynamic textures, the visualization quality fell short of expectations. Modern game engines should be used here in the future. The interaction of the 3D prints using built-in touch sensors worked very well. The effort to program the Arduino computers was very low. The approach presented is therefore sensible in its entirety, but can still be expanded in a number of details according to the above explanations. It will also be interesting to compare the presented approach of AR front projection with the use of augmented reality smart glass, also in combination with 3D printing and physical model construction.

References

Bimber, O., Wetzstein, G., Emmerling, A., & Nitschke, C. (2005, October). Enabling view-dependent stereoscopic projection in real environments. In *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'05*), pp. 14-23. IEEE., https://doi.org/10.1109/ISMAR.2005.27.

Ewing, M. (2019). Bugatti Design Director Achim Anscheidt Discusses Virtual Reality Design of $9 Million Centodieci. In: Forbes, 31.08.2019, available online: https://www.forbes.com/sites/markewing/2019/08/31/bugatti-design-director-achim-anscheidt-discusses-virtual-reality-design-of-9-million-centodieci/, last accessed 12.10.2021

Iiwai, D. (2016). Projection Mapping Technologies for AR. In: 23rd International Display Workshops in conjunction with Asia Display 2016. *Proceedings of International Display Workshops (IDW)*, pp. 1076-1078.

Glon, R. (2020). Out with the clay, in with the VR: Bugatti's design studio is all digital Bugatti's head of design told us why virtual reality is better. In: autoblog, 20.02.2020, available online: https://www.autoblog.com/2020/02/20/bugatti-design-studio-virtual-reality-vr/?guccounter=2, last accessed 25.7.2020

Runde, C. (2020). Applikationszentrum V/AR. Bericht #05. Narrative Applikationen: Hybrid Design Journey, *Virtual Dimension Center (VDC): Fellbach*, 10.08.2020, https://doi.org/10.6084/m9.figshare.12821351.

Runde, C. (2020). Applikationszentrum V/AR. Bericht #09. Narrative Applikationen: Projektionsbasierte Erweiterte Realität in Designanwendungen, *Virtual Dimension Center (VDC): Fellbach*, 17.11.2020, https://doi.org/10.6084/m9.figshare.13241783.

Stark, R., Beckmann-Dobrev, B. (2009). Smart Hybrid Prototyping: Ein interdisziplinärer Ansatz zur multimodalen funktionalen Absicherung mechatronischer Systeme am Beispiel einer PKW-Heckklappe, *3. Grazer Symposium Virtuelles Fahrzeug, Graz, Austria*, 6.-7.5.2009.

Author Index and Table of Figures

Author Index

Table of Figures

Series title and number

VTT Technology 395

Title	**EuroXR 2021** Proceedings of the Virtual EuroXR Conference
Author(s)	Kaj Helin, Jérôme Parrot & Sara Arlati (eds.)
Abstract	The focus of EuroXR 2021 is to present novel Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) technologies, including software systems, display technology, interaction devices, and applications. Besides scientific papers reporting on new advances in the VR/AR/MR interaction technologies, the conference programme includes application-oriented presentations, creating a unique opportunity for participants to network, discuss, and share the latest innovations around commercial and research applications. As in previous years, we welcome industrial and academic exhibitors, as well as sponsors, all within the same exhibition area, to connect with our community. Our major priority is to provide authors the opportunity to prestigiously disseminate their innovative work within the wide community of end-users, from large scale industries to SMEs.
ISBN, ISSN, URN	ISBN 978-951-38-8756-8 ISSN-L 2242-1211 ISSN 2242-122X (Online) DOI: 10.32040/2242-122X.2021.T395
Date	November 2021
Language	English
Pages	67 p.
Name of the project	
Commissioned by	
Keywords	VR/AR/MR technologies, software systems, display technology, interaction devices, and applications
Publisher	VTT Technical Research Centre of Finland Ltd P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111, https://www.vttresearch.com

EuroXR 2021

Proceedings of the Virtual EuroXR Conference

The 18th EuroXR International Conference – EuroXR 2021 – taking place on 24-26 November 2021 organized by the CNR-STIIMA institute in Milan, Italy. The conference follows a series of successful European VR/AR conferences taking place since 2004 and known as INTUITION, JVRC and recently EuroVR (Bemen 2014, Lecco 2015, Athens 2016, Laval 2017, London 2018, Tallinn 2019 and Valencia 2020).

EuroXR 2021 will bring together people from research, industry, and commerce. Its members include technology developers, suppliers, and all those interested in Virtual Reality (VR), Mixed Reality (MR), including Augmented Virtuality (AV) and Augmented Reality (AR), and more globally 3D user interfaces, to exchange knowledge and share experiences, new results and applications, enjoy live demonstrations of current and emerging technologies, and form collaborations for future work.

ISBN 978-951-38-8756-8
ISSN-L 2242-1211
ISSN 2242-122X (Online)
DOI: 10.32040/2242-122X.2021.T395

VTT beyond the obvious