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INTERACTIVE IMMERSIVE ENGINEERING SYSTEM FOR DISTANT COLLABORATION

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Abstract

Complex products consisting of various components are designed in collaboration of multi-disciplinary engineering teams with different expertise. Expert groups involved in the development process are possibly based at geographically distributed locations. The purpose of this contribution therefore is the development of a framework, enhancing the quality of communication and facilitating the exchange of information and expertise in engineering projects over distance. This framework provides the capability to visualise a product model and the avatars of distant people in one shared immersive virtual environment. Furthermore the integration of product information exceeding the pure geometry and features for direct modification of the visualised product are achieved through the connection to CAD software. The intuitive interaction interface utilises hand gestures based on normal physical interaction with real objects. Being able to see both the 3D model and the other participant in one shared virtual environment creates a natural communication and interaction process, without being distracted by new communication or interaction methods forced by the technology.

Keywords: Collaborative design, Communication, Human-Computer Interaction, Virtual Reality

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1 INTRODUCTION

During product development process different components of the product are designed by multi-disciplinary engineering teams with diverse competences. Thereby the collaboration and the communication between different internal and external stakeholders have an enormous impact onto the product innovation and quality. Chryssolouris et al. (2009) delineates that sharing product design knowledge and resolving problems mostly happens during physical meetings or via email and telephone discussions. The expert groups involved in the development process are possibly based at geographically distributed locations (Chryssolouris, 2009). Note that a distinction can be made between cooperative engineering with multiple stakeholders on one shared physical location and on multiple remote locations, the present paper focusses on.

Email, telephone and video conference discussions obviously provide a poorer quality in communication than physical meetings. This loss is resulting from an absence of shared interactive visualisation, e. g. a (virtual) product or the progress of the development process, and the lack of reality in human communication, e. g. through missing facial expression and gaze awareness.

Within the product development process the methods of Virtual Reality (VR) are utilised to provide the users realistic visualisations and advanced Human-Computer-Interfaces (Menck et al., 2012). In an often used method for design review, VR is used for an immersive visualisation of the product, serving as a basis for interdisciplinary discussions. Those reviews are normally physical meetings. Both issues of distant discussions, the lack of shared interactive visualisation as well as the lack of reality in human communication, could be overcome by transferring a realistic representation of the distant person into the virtual scene.

The purpose of this contribution therefore is the development of a framework combining the stereoscopic visualisation of an interactive product model with the presence of distant participants. To enhance the possibilities during design review, the integration of product information exceeding the pure geometry and features for direct modification of the product is essential. Therefore, the visualisation is connected to computer-aided design (CAD) software. In order to facilitate the handling of the framework, the interaction has to be implemented through an intuitive user interface.

We first discuss different approaches considering collaborative engineering in virtual environments (VE) and set up the requirements of the system. Furthermore our framework is described including the functionalities standing behind the cooperative engineering system. To prove the usability of the framework, a case study of a virtual products assembly process is utilised. The present paper ends with a conclusion, future prospects and reasonable extensions.

2 BASICS OF COOPERATIVE ENGINEERING SYSTEMS

The need and willingness to work together in an engineering process occurs mainly in development projects involving a wide variety of expertise. All this expertise should be used to its fullest extent, and combined with others, without losing relevant information due to translation errors. In these situations, the knowledge of each individual is of great value, and can contribute in a positive way to the final result. The need for a company to integrate multiple disciplines in engineering processes is growing due to the competitive market and need for sustainable manufacturing (Váncza et al, 2011). Additionally the complexity in engineering projects is constantly growing, and demands new flexible approaches to handle with dynamic processes (ElMaraghy, 2012) and less predictable communication needs.

To achieve a useful cooperation between engineers it is essential to use contemporary information and communication technologies to facilitate each stakeholder to communicate and cooperate with others. In addition, the (direct) communication between the different users should be facilitated and stimulated as much as possible. Features like real-time adjustments, (personalised) information layers and annotation possibilities are indispensable in these processes.

2.1 Approaches of telepresence in virtual environments

In engineering projects VR is one of the used approaches to stimulate and facilitate cooperation. It can offer a visual representation of the current state of the development, by combining the currently available information into one 3D environment. Virtual environments make it possible to experience the result of the project without having the need to build physical models. (Blach, 2008)

The available VR techniques have greatly expanded in recent years and also became more accessible to a wider audience through lower costs. In the early years of VR the use was reserved to experts on the technology, and the preparation of use took a lot of time. This is slowly changing over time due to the development of new equipment, but still equipment is developed often as a single tool, while the use requires a combination of more devices. The purpose of VR in development processes is stimulation of the senses in such a way that the "new reality" is imitated as much as possible. The emphasis is in most situations on the visualisation of models on large surfaces, and displaying the results in 3D. This often results in creating virtual prototypes instead of physical prototypes (Cecil, 2005).

Ottosson (2002) denoted that communication with distributed colleagues is one field of application of VR for product development. Quite some time ago, Gibbs et al. (1999) had the idea of establishing a teleconferencing system, supporting face to face meetings, although the participants were geographically separated. It combines user tracking and wall-sized real-time viewing of distant participants. The result is an environment with real and virtual content, giving the illusion of looking into a room, where the distant person is e. g. sitting behind a desk.

Furthermore a current approach of bringing distant people together in an immersive environment was presented by Beck et al. (2013). This system utilises a cluster of Microsoft Kinect sensors to reconstruct avatars from a group of people. These avatars are then displayed in a virtual scene and the whole group can e. g. jointly explore a virtual city. A large one sided multi-user three-dimensional (3D) display provides the visualisation. The interaction capabilities are implemented through the utilisation of a stationary input device mainly developed for navigation purposes.

Kurillo and Bajcsy (2013) point out several application areas of teleimmersion technology. They have applied their teleimmersive framework for example to geoscientific experiments and remote health care delivery.

The idea of bringing distant face to face meetings together with the stereoscopic visualisation of the product would heavily enhance the collaboration capabilities over distance. In cooperative engineering multiple phases can be devised in which the use of VR in combination with copresence may be relevant. The way VR is used will often be different within each phase, due to other desired functionality and goals.

2.2 Requirements of the proposed system

The most common and easiest to use form of VR is to graphically visualise the current state of the product. This is often complemented with the possibility to comment on the visualisation as part of the virtual environment. From this functionality, a supporting method and use situation can be created, in which a distinction can be made in the techniques required for communication between the participants at the local and remote location, and the techniques needed for visualisation and interaction with the digital data. In a first step, the requirements of the communication side and thereafter those of the visualisation and interaction side are considered. The mentioned requirements are mainly derived from relevant literature described above and findings during the work on this topic.

To facilitate the distant communication with other participants to be as life-like as possible, it is desirable to visualise all of the participants in the same shared virtual environment. Therefore, the users have to be captured as three-dimensional pictures and transferred into the scene. The visualisation of those avatars makes it possible to look at each other, and to know what the other participant sees. The behaviour and emotions of the participants, like facial expression and gaze awareness, can be recognised and included into the communication process. In addition, it is possible to blank out the background of the remote location in the shared environment, which prevents the users from being distracted by the background noise of the other location. Besides a visual representation of each participant, a voice transmission enables spoken communication between each location. The microphones have to be positioned in such a way that as little background noise as possible is transmitted to other participants. An advanced solution for audio output would be a system,

in which the sound comes from the direction the speaking person is actually positioned within the virtual scene.
Summary of the communication requirements:

- Real size visualisation of the one or more distant participant(s)
- Image quality high enough to distinguish facial expressions
- Blank out the background of remote locations
- Audio transfer between different physical locations

Selecting the best fitting approach for interaction with digital data is strongly related to the chosen visualisation technology (Bowman, 2007). To have the opportunity of estimating the position of a part of the product in the virtual space, e. g. if the user wants to point on a detail, a head tracked stereoscopic vision is essential. Additionally it can be taken advantage of the capabilities of advanced Human-Computer-Interfaces.
In order to develop the best possible intuitive to use collaboration system, it is important that the threshold for the use is kept as low as possible. In addition, the communication quality can be enhanced by giving the user the feeling of direct interaction with other participants and the product, without giving too much notice to the used equipment. The technology used should be as unobtrusive as possible, and should require little or no preparation and specific expertise for use.
One disadvantage of this common design reviews in VR is that the visualised model is often an on beforehand prepared model based on the data available before the meeting. The results of the meeting are not directly influencing the model, but have to be processed afterwards. To get a true cooperative setting during meetings, it must be possible to manipulate and adjust the configuration or assembly of (3D) models for the participants. This requires much of the system in terms of interaction possibilities, and co-operation with existing data. To enable these capabilities, a geometric model database has to be available through a CAD program, allowing changing the parameters of the model.
To be able to modify and manipulate the model an intuitive and easy to use interaction interface has to be integrated. For keeping the distraction coming from multiple input devices as low as possible the ideal solution would be a device with integrated functionality. On the one hand this equipment should support capturing the 3D avatars and on the other hand tracking the head position and the movements of the participants. To guarantee that every person in the session can participate and bring thinking and expertise in, the interaction must provide a possibility to simply change the operator. The operator is the person, who is capable of manipulating and modifying the virtual content, like sitting in front of a PC controlling the mouse. At the time, only one person can obtain the role of the operator.
Due to the descriptions above, here is a summary of the visualisation and interaction requirements:

- Head tracked stereoscopic visualisation
- The threshold for using the system has to be kept as low as possible
- Interactive and modifiable product data
- Intuitive and easy to use interaction interface
- Every person should be able to participate. At the time, only one person can obtain the role of the operator, who can modify and manipulate the model
- Integrated functionality for renouncing multiple input devices

2.3 Methodology and implementation

The proposed system in this paper is focussed on cooperative engineering projects. The currently used approached in these type of projects differ enormously, and no standard method or process can be defined. Nevertheless fundamental aspects of collaborative work between different engineers form the basis of our approach. An important aspect to maintain in the development of the system is not to formalize the exact method how the user should use the system. The proposed solution should offer new possibilities for cooperation, but should not describe exactly how to implement and use it. The possible use cases are therefore not completely known on beforehand, and therefore the system can be altered regarding the expectations.

3 DISTRIBUTED COOPERATIVE ENGINEERING SYSTEM

3.1 The shared virtual environment

The basic elements of the setup are the two displaced powerwalls, providing a stereoscopic projection, for visualising the entire content of the virtual scene (depicted in Figure 1 left and middle). To create a shared virtual environment, both powerwalls are virtually arranged towards each other in the virtual scene, so that the projection screen provides a "window" into the distant VR system (depicted in Figure 1 right). The screens must have a certain distance to create the "interaction space" (see Figure 1), where persons from both VR systems can interact with the model, for e. g. pointing on a CAD feature or surface.

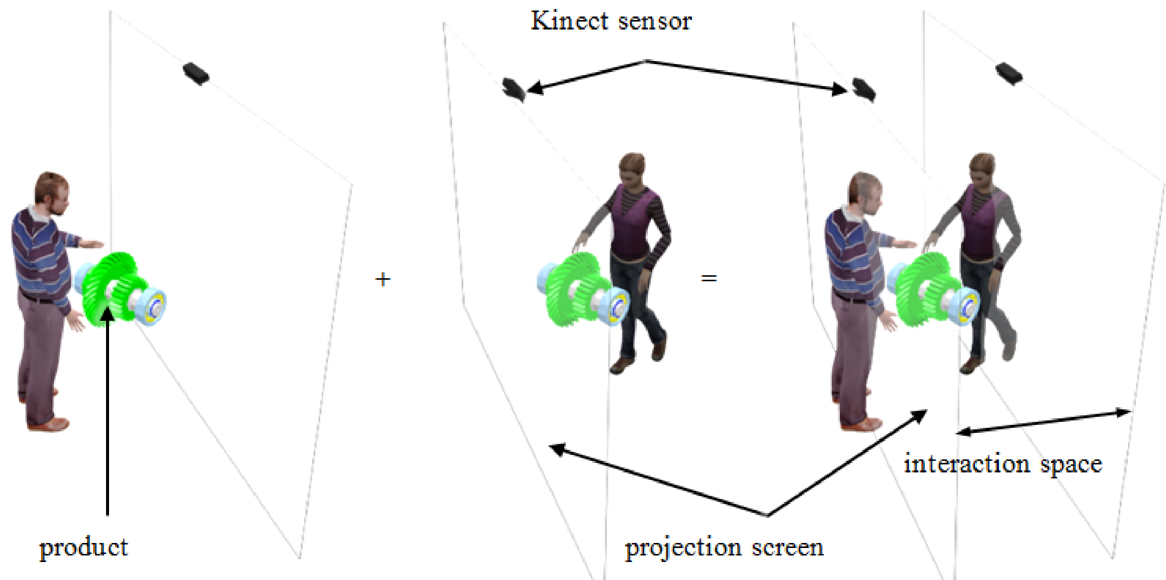

Figure 1. Single virtual environment (left, middle); shared virtual environment (right)

The content of the virtual scene includes the model of the reviewed product and point clouds representing the distant participants. That implies the group of people in one VR system is seeing the distant group standing in front of and turned towards them, when facing the projection screen. Each captured person is represented in 1:1 scale real size stereoscopic vision. The point cloud utilised therefor, is calculated with the help of a depth and a colour image that is obtained from the Microsoft Kinect sensor. This sensor fulfils several of the requirements, developed above. Amongst other things, it acquires data for real size visualisation of the distant participants and it can capture the audio to be transferred to the distant persons. The sensor is attached to the top of each projection screen. It has been deliberately decided to use one Kinect sensor, resulting in a point cloud that is suitable for looking at it from the front. The back of the persons is not mapped into the displaced VR system, because it is not visible from the local opponents. The decision for using only one Kinect sensor per VR system was made due to reduced time for calculation and TCP transfer of less data. Besides gaining the point cloud of one person or a group of people, the Kinect sensor also has the purpose to provide tracking data of the participants to enable the use of an intuitive markerless interaction technique. Head tracking of multiple people is also supported by the sensor. Thereby the perspective onto the content of the scene, like the discussion opponents and product model, can be adapted to the position of the user.
Audio is acquired from the Kinect sensors microphone array. Transferring the audio could be done over the network connection. Instead of focussing on developing a module to transfer audio, external third-party software should be utilised.

3.2 Avatars in the virtual scene

After developing the setup of the shared virtual environment the next step is the extension of the framework presented in Fechter et al. (2014). This software builds up on three software modules: one

for CAD modelling, one for visualisation together with interaction handling and a third one undertaking the task of providing interaction data from the Microsoft Kinect sensor. The CAD functions are put into practice through the utilisation of an open source CAD system. FreeCAD provides several advantageous features like handling STEP data to facilitate exchanging models with commercial CAD software and exporting the CAD model to a tessellated 3D geometry that can be processed by the visualisation module. Combining VR Juggler and OpenSceneGraph (OSG) results in a powerful development platform that offers efficient visualisation and support for clustering the graphics calculation. The interaction data is spread in the network through a Virtual Reality Peripheral Network (VRPN) server. Altogether the theoretically possible extent for modifications of the CAD model is only limited through the capabilities of the FreeCAD software itself. The CAD functionality made available in the VE is the insertion of assembly constraints. (Fechter et al., 2014)
The software sub module, named "point cloud server", has the task of computing and distributing the point cloud representing the design review participants. It runs in a parallel thread to the interaction data processing. The data for the avatars is calculated from the depth image and the RGB image delivered by the Kinect device. For each tracked pixel the position in space is stored as a vector and its colour is stored in RGBA format. A transmission control protocol (TCP) connection is utilised to send those data packages from the point cloud server thread to the opposing powerwall (depicted as black arrows in Figure 2). The interaction data, including the position and rotation data as well as the button status values, are directed towards each visualisation node of the virtual environment (grey arrows).
As a result we receive a modular structured software concept that supports the manipulation of CAD models in a virtual environment through an intuitive markerless interaction concept. Additionally it provides a distributed shared virtual environment including the avatars of the distant participants.

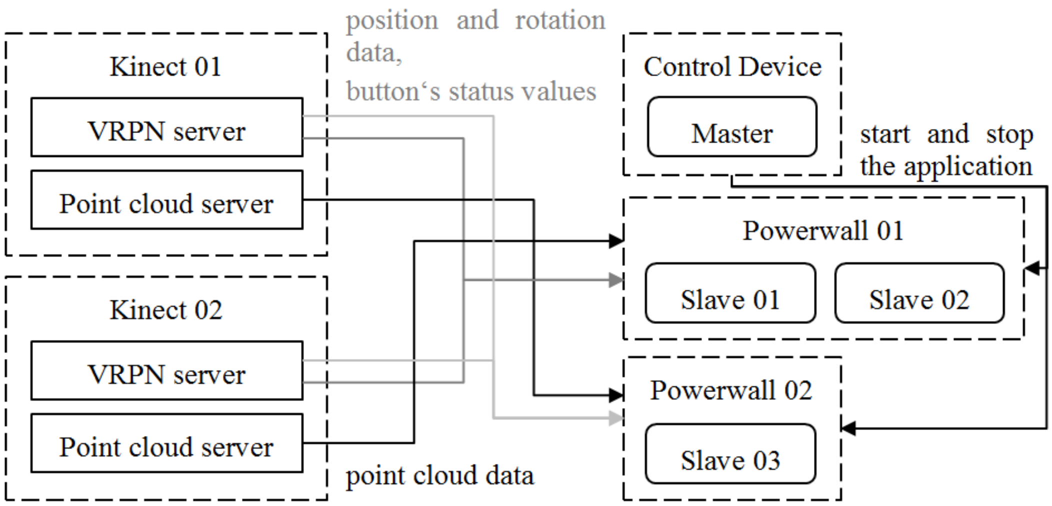

Figure 2. Data flow for the point cloud and interaction data distribution

3.3 Gestural interaction

To receive a functional concept the last piece missing is an intuitive interaction interface enabling every single member of the discussion group to operate on the system and to participate in the design review. The system should be potentially manipulable by every present person, but there should be only one master user (operator) that can manipulate the scene content at the same time. Therefore, a concept is needed that provides the functionality of interchanging the master user status between the participants.
The basic interaction concept builds up on Fechter et al. (2014) and is not standing in the focus of the present paper. Hand gestures and movements are utilised to implement the three basic components of interaction in virtual environments: selection/manipulation, navigation and system control (Bowman et al., 2001). The scenes' content can be manipulated by pre-selecting an element through hand movement and making a fist with the right hand to translate the object or making a fist with both hands to rotate the object. Picking an element is done through closing and opening the right hand in a time interval smaller than 0.4 seconds. (Fechter et al., 2014)

Due to developing a single user interaction concept in Fechter et al. (2014), there are no functionalities that offer support for multi-user applications. Therefore, an interaction concept for switching the master user has to be developed. Since the basic concept harnesses the power of a Kinect sensor, it is obvious to use a gesture. To guarantee that everybody is capable of performing the gesture for switching the master user, it must be simple and to prevent any disturbance in the workflow during a design review it must be safe from being performed accidentally. Considering these requirements, the gesture that was chosen for master user registration is holding both hands 20 centimetres over one's head. Everybody should be able to learn and to perform this gesture easily; on the other hand it is unlikely that one raises his hands over the head accidentally or the sensor wrongly detects that pose.

4 CASE STUDY: COOPERATIVE ASSEMBLY TRIAL

In order to show the functionality of the developed shared Virtual Reality concept in practical use, the discussion about the assembly process of a product, in this case a gearbox, serves as an example. The decision for this demonstrator was taken due to three reasons. First, an assembly usually consists of several components that are designed by various experts from different departments. Secondly, the additional value offered through the presence of a CAD system operating in the background can be pointed out. And thirdly, the simplicity and the intuitiveness of the interaction interface can prove its usability.

The first step is to visualise the distant people participating in the session. In Figure 3 a point cloud of a distant person is depicted from different point of views. In the left picture the person is depicted from the front, showing a good result. The white area underneath the chin is a result of occlusion, because the location of the depth camera is on the top of the projection screen looking downwards on the person. Therefore, the camera cannot see area at the neck. The right picture in Figure 3 is the same participant at the same time from another viewpoint that is located at the side. The local user could now move around the point cloud in the virtual scene and would get the respective sight onto the depictured person.

Furthermore, a master user has to be defined through raising the hands 20 centimetres over his head. This user is the operator until another participant raises the hands and becomes the master user.

Figure 3. Visualisation of the distant participant; from the front (left), from the side (right)

Note that the two following figures consist of pictures taken from the perspective of a local session participant that is looking at the scene including an avatar from a distant person.

At the beginning of the assembly process the lower housing of the gearbox is located between the participants from the two VR systems. An import menu (depictured in Figure 4, left) that contains various subassemblies can be opened by the master user. Selecting an element through hand gestures leads to importing the subassembly into the CAD system and the virtual scene. Thereafter the drive shaft assembly can be moved and rotated in the virtual scene. The participants can discuss about the geometry, possible ways of manufacturing or the subsequent assembly procedure. The great benefit is that they can directly point at faces, edges or features like a drilling hole or a working surface. Every person within the virtual scene can see the component pointed on. Misunderstandings will be avoided through a way of communication that is very similar to reality. Figure 4 (middle) shows the distant person pointing onto a cylindrical surface that should be used for assembling the drive shaft component to the lower housing. In the right element of Figure 4, the same pose is depicted from a side view. It illustrates the spatiality of the avatar. The left hand of the user is located over the drive shaft assembly within the virtual scene.

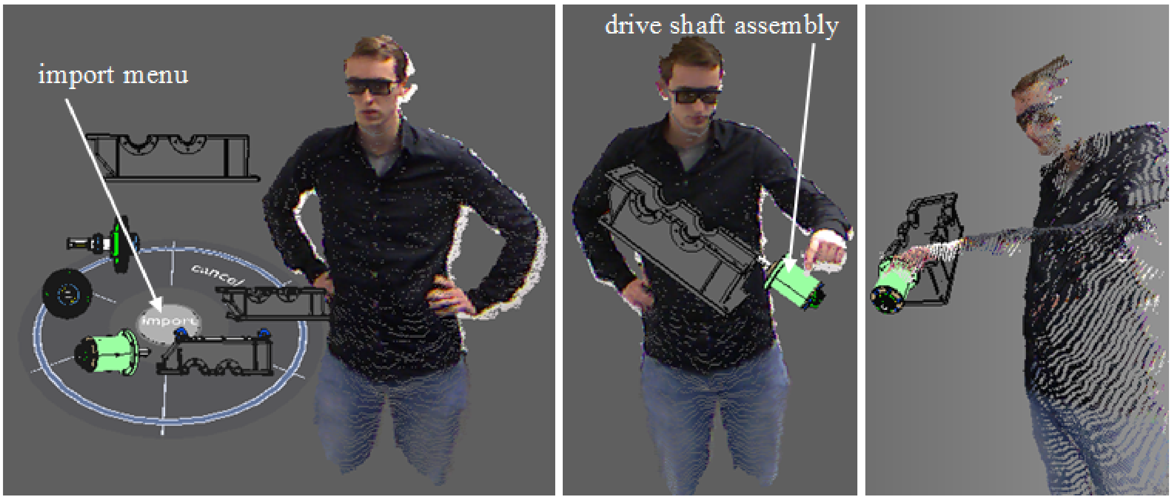

Figure 4. Import menu from the local users view (left); pointing on a surface from the local users view (middle) and from the side (right)

Afterwards the operator selects the indicated surface and adds a constraint which profits from the 3D interaction concept. It was developed in Fechter et al. (2014) to apply a cylindrical surface to another cylindrical surface that has a very similar radius. The precondition for this to happen is that the rotations of the central axes of both faces are approximately the same and the position of the surfaces is similar. If the system detects two matching surfaces, the subassembly automatically docks to the appropriate position, the green bounding box shows up for visual feedback and a pie menu appears. After flipping the central axis and confirming the constraint the drive shaft subassembly is movable on and rotatable around this axis. If the local master user would not understand how to assemble the drive shaft, the distant user could become the master user through raising his hands.

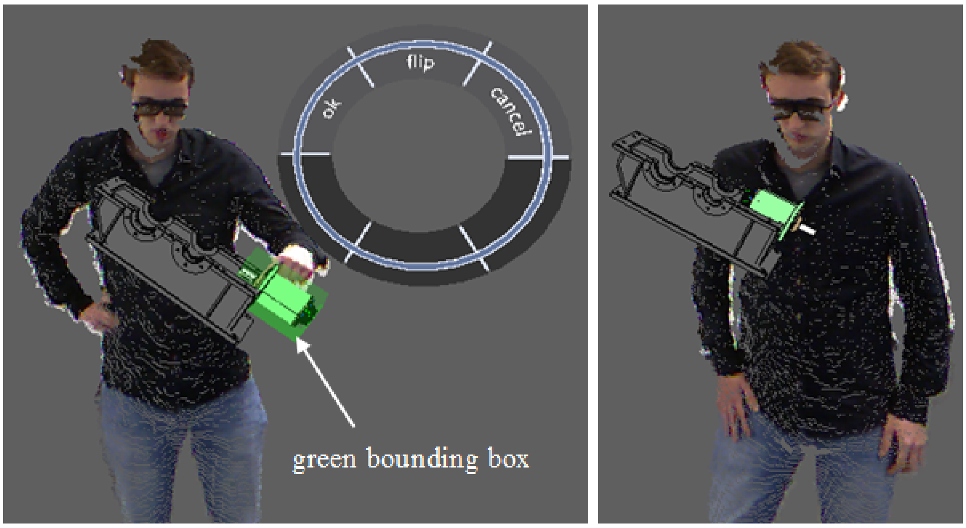

Figure 5. Adding a constraint (left); mounted drive shaft assembly (right)

Finally, when all operations on the assembly are carried out (see Figure 6), the resulting CAD model can be saved for further consideration.

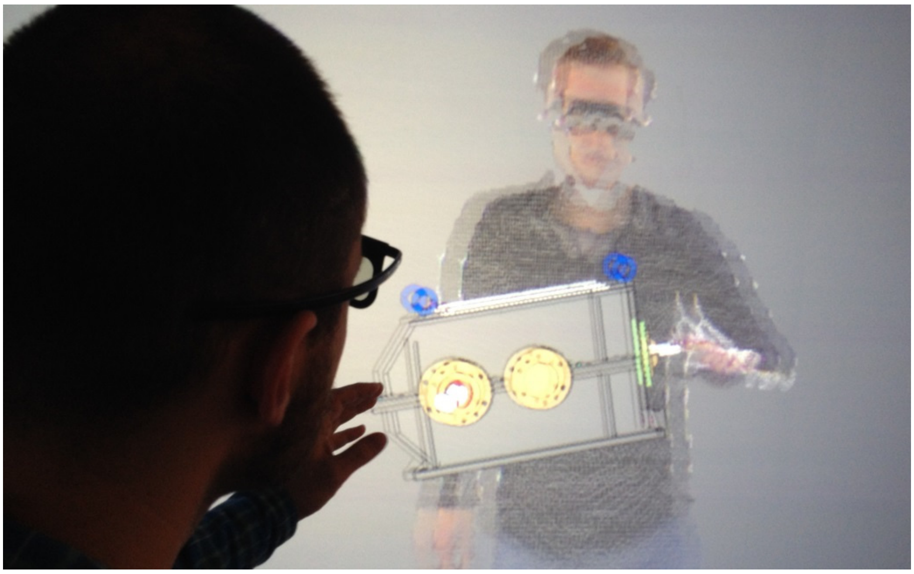

Figure 6. Distant participant from the local participants view.

It is shown that the combined visualisation of the distant discussion opponents and the developed product in one virtual scene enhances the communication quality massively. Instead of excessive describing which feature of the CAD model is meant during a telephone meeting, in the VE the user can just point on it with his hands.

5 CONCLUSION AND OUTLOOK

The idea presented in this paper is to combine the capabilities of an immersive visualisation with telepresence to support interactive distant Virtual Reality design review. The developed framework should serve as a tool to facilitate exchanging information, expertise and point of views in engineering projects. Within this system it is possible to visualise the product model and the distant session participants in one shared virtual environment. The people can directly point onto the components of the virtual product, they want to discuss about. Furthermore the framework offers possibilities for geometry modifications, due to the availability of CAD data in the VE. The intuitive interaction interface utilises hand gestures based on normal physical interaction with real objects. Being able to see both the 3D model and the other participant in one shared virtual environment creates a natural communication and interaction process, without being distracted by new communication or interaction methods forced by the technology. The system does not dictate exactly how people should use it during engineering tasks, but it offers new possibilities which can be integrated in the used methodology of multiple projects.
This first version of the system will be the starting point for further development on the offered functionality. An evaluation of the framework has to be carried out with multiple users. Based on the feedback and the results, possible enhancements in terms of tracking data processing and distribution have to be considered. Also an extension enabling the increase of the number of remote locations has to be developed in the near future. This will also implicate new challenges regarding e.g. shared data sources, intellectual property, annotation storage, version history and (un)desirable pre-defined hierarchy.

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