Transdisciplinarity and the Future of Engineering
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Simultaneous Interdisciplinary Teamwork on Digital Twins in a 3D Collaborative Environment

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Abstract. Digital twins of product and production processes are being used more and more frequently. The reason for this are the benefits for all departments involved. Therefore, it is not only important to share an IT platform as a 3D collaboration environment with uniform data structures, so all employees can work with the same database. As well it is important to give all interdisciplinary departments the opportunity to work in a common simulation and interact with it as a digital twin of the product and production process. Each department must be enabled to add their information, to collaboratively design a working digital twin of the real product. In addition, it must be possible for several people to work together simultaneously in a shared virtual environment. Voice chat, video chat and graphic simulation features such as virtual and augmented reality must be integrated to enable collaboration and interaction with the digital twin. Another challenge is to allow multiple participants to take part in these virtual meetings simultaneously, even if they use different end devices. The paper presents a 3D collaboration environment developed in research projects based on the development environment for graphic simulations Unity3D, with the ability to include various user concepts and functions for the specialist departments and allows access for the employees as a multi-user application on different end devices.

Keywords. Digital Twin, 3D Collaboration Environment, Interactive Simulation, Multi-User Application, Digital Engineering, Virtual Reality, Augmented Reality

Introduction

The usage of digital twins of production systems is becoming a daily routine in many engineering teams, because it increases the efficiency of the development process by enabling optimization of the system concept in a very early stage of the development process. This way, errors can be recognized and fixed even before an actual production of a system. This decreases the error rate and increases the systainability of a production machine. However working with a digital twin is often complicated and only possible for professionals that are working in a very specific engineering department. It is not common, that those digital twins are actually used in all engineering disciplines. To enable this, it is mandatory, that all engineering disciplines are working with the same database. A trail to create an IT system, that all disciplines can work with, is presented in [1]. This publication presents an attempt to enable simultaneous realtime collaboration with the digital twin of a production system for all engineering disciplines. The goal is to use networking and immersive technologies to create an interactive and accurate simulation of the actual production machine, that can be used from any participant of the development process. The advantage of immersive technologies is, that they put users in a natural perspective, what enables a better perception of design, ergonomics and constructionability [2]. It is also stated, that working in Virtual Reality (VR) does increase efficiency, because there are less distractions for a professional, if he is wearing a VR headset [3]. The system should also be used by “non-professionals” that are not necessarily familiar with things like CAD-software and numerical control interfaces. Lowering the barrier by working with a digital twin, the researchers hope to contribute to the increasing effectiveness of engineering processes, as more people will be able to validate designs and review functions. This article does not contain a fully available commercial system, but a proof-of-concept of an accurate digital twin framework, that will allow simultaneous teamwork over all disciplines.

1. Relevant work

The use of immersive technologies such as virtual reality for engineering purposes is not a new concept. There have been many attempts to use VR technologies to interact with digital copies of the actual technical product. A study on impacts of VR for design reviews is described in [4], stating that it is a useful tool for the design process, because it helps to give a more intuitive feeling for dimensions and especially enables non-experts in modern CAD-software to review a design. However, the participants of the project declare one problem of VR is the isolation from their colleagues, so it would be more helpful if the whole team could join in a VR conference to simultaneously analyse the design in a collaborative way. One approach to realise a real time multi-user VR application for reviewing designs and discussing them face to face is presented in [11]. In a small experiment, it was tested, how the VR-applications influences the performance of teams to find design errors. The results state, that the teams who used a VR application to find design errors outperformed Teams that used a classic design review process approach using CAD and 2D-drawings. [5] attempted to use a VR system for assembly studies in an early design phase of a product, and it has been found that VR does provide an intuitive way for assembly and ergonimic tests, however some difficulties are also seen in converting the data from CAD to VR as well as accurate physical modelling. Another application field of VR besides the design review of machines, is factory layout planning. One example is [6], where the researchers create a system to plan layouts in 2D and 3D as well as in VR. There have also been several trails to enable collaboration in VR. A study examining the impact of virtual reality collaboration on engineering is described in [10]. It states that virtual reality is helpful for global engineering teams because it allows users to take their own perspective, which gives the software greater value for collaboration than text messages, voice calls or two-dimensional visualizations on a screen.

2. Demands and use cases of interdisciplinary collaboration

Since the goal is to bring all departments together and collaborate on the same plattform across the globe, it is important to know the demands that each departmant has towards a digital twin. So for this project there were use cases created for the following branches, that might be making use of a digital twin:

- Mechanical Engineering
- Information Technologies
- Production Planning
- Service
- Sales

These demands are described for each discipline separateley, but of course, the goal is to enable collaboration between them.

2.1. Mechanical Engineering

As already stated previously, the main purpose of a digital twin for mechanical engineers is to evaluate their design visually. Virtual Reality may bring the biggest advantages to mechanical engineering, because it is able to let them explore a model through a human perspective. This makes it very easy for them to get an impression of the actual dimensions, the design as well as the ergonomics of the machine. For assembly testing, features like collision detection will be needed. In order to enable CAD laymen to validate the design, a simple and intuitive user concept is required so, for example, production workers can also provide direct feedback on the design and ergonomics of the model.

2.2. Information Technologies

The IT department will be using a digital twin mostly for developing and testing their programs, which are going to be used in the production process later. A digital twin will add a lot of value here, because it enables IT engineers to start development of their software earlier, and do more testing, which will result in a lower error rate at the start of production. Another advantage for the IT department is, that IT engineers get a better understanding of the actual production process.

2.3. Production Planning

A digital twin also helps production planning engineers to plan the ressources and the material flow, calculate and optimise production times and therefore collaborate with the other departments to achieve an efficient production process. Subsequent changes in the production line can be costly, so it is important to find errors as early as possible. Another usage for production planners is the ability to explore their production plant in VR, which also gives them a much better impression of the overall system as well as the distances that workers will have to cover in the process.

2.4. Service

The service department can also make use of an accessible digital twin. Service staff can be trained on the machine in VR, while simulating various events. But they can also look for design faults by trying to reconstruct faults in the field to find a solution. Wearing an Augmented Reality (AR) headset, a service technician in the field can be supported by a video stream from an expert in the headoffice showing the work steps on the digital twin. This would enable the highly specialised service members to stay in the headoffice and help technicians all over the world without having to travel.

2.5. Sales

Not necessarily an Engineering department, but sales managers can also take advantage of a digital twin. They can use it for simulations and visualizations to show a customer the capabilities of the product. Another plus for sales is that interacting with a digital twin in VR is still not very common to most people, so it helps to differentiate from competitors.

3. Requirements for the collaborative environment

The last paragraph discusses the potential use cases of a collaborative environment for each department. Analysing these requirements lead to 3 key functions that a digital twin must have:

- Powerful visualization
- Interface for commercial numerical control software
- Accurate physical model of the real machine

An attempt to describe a digital twin that can provide these functions can be found in [1]. However, the focus of this article is on describing how a digital twin can be made accessible to all participants in the product life cycle. In the last chapter the potential use cases of collaborative digital twins were examined. Based on these references, the requirements for the collaboration environment can be derived. The most basic requirement to enable collaboration, of course, is a stable networking component. To enhance a fluent user experience, a User Datagram Protocol (UDP) networking approach was chosen. Regarding the user concepts, there must be taken into consideration, that different options are needed. For example exploring a digital twin in VR may be a great help for the mechanical engineers, but it is not necessarily helpful for the IT department, as they work on their programmes simultaneously on the computer. Also, it is still not very common, that every engineer will have access to a VR or AR headset any time or place. So it should be possible to join with different types of hardware. The types of hardware that will need to be supported were determined as follows:

- Virtual Reality headset
- Personal computer with screen
- Mobile device (smartphone/tablet computer)
- Augmented Reality headset

Of course, not all kind of hardware will provide the same functionalities, so the user concepts are carefully designed for each device. The following table shows an overview of the hardware, where it could be used and what kind of software features will be required.

Table 1. The styles defined in IOSPressBookArticle.

Device	Use for	Required features
VR Headset	General inspection	Good visual quality of the model;
	Interact with digital twin	Interfaces to interact with the model in VR;
	Collaborate in meetings	Streaming user movements / voice chats / Display avatars of other users
Personal Computer with Screen	General inspection	Good visual quality of the model;
	Software engineering	Interface for industrial control software
	Attend meetings	Move within the model, video streaming, voice chat
Mobile Devices	General inspection Attend meetings	Move within the model, video streaming, voice chat
Augmented Reality Headset	Supporting/ training service staff on site without physical presence of an expert	Video streaming in both directions Voice chat

4. Architecture and function of the collaborative environment

The core of the IT system used within this project is Unity3D. Unity3D was originally developed as a platform for game development, but in recent years, Unity3D has become very popular for scientific and industrial approaches to graphical visualization. It is free to use for non-profit organizations and the ressources, that already exist, make it easy to start with the development. It is also very useful that Unity3D is open for any custom developed extensions, so interfaces for basically any other software can be created.

As mentioned previously, a system for an accurate digital twin is described in [1]. Figure 1 shows a schematic, that describes the architecture of a digital twin of a production system. Unity3D does have a native physics engine, but it does compromise accuracy for real time ability [7], which is not ideal for scientific projects. So an interface to the software Virtuos was created. Virtuos is a program to create a digital twin with an accurate mathematical model, that describes the dynamic of motors, hydraulic cylinders and other actors of a production system. Besides that physical component, there are also interfaces for commercial numerical control software as TwinCat (for PLCs) and Kuka Office (for robot arms).

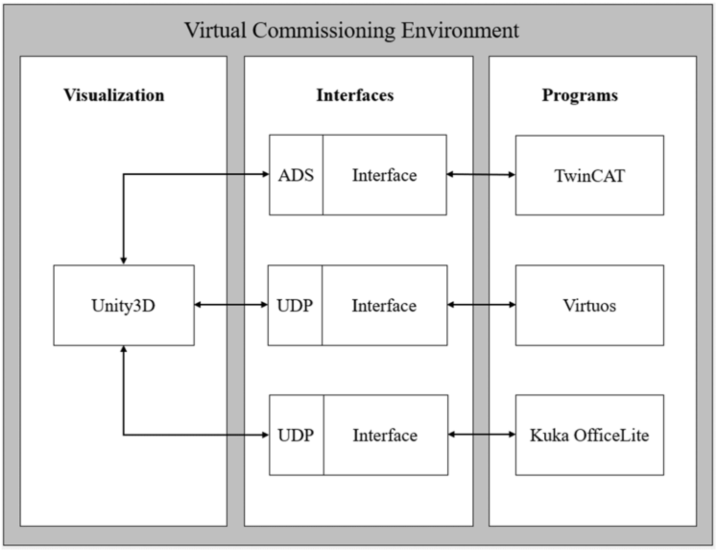


Figure 1 Architecture of a digital twin [1]

The challenge is to make this IT system of a digital twin accessible and ready for a multi-user application. It is important to define the architecture to make sure that calculations of the different users do not interfere with each other. For the multi-user application, a server-client architecture, where the hosting server can also join the application is chosen. As shown in Figure 2, the hosting participant provides the infrastructure for all calculations of the digital twin (physics, control interfaces, etc). The other participants connect to the hosting server and only stream their movements, camera feed, voice feed and actions to the server application. To provide a good user experience, a server with strong hardware is necessary, because calculating all events of a digital twin is computationally intense.

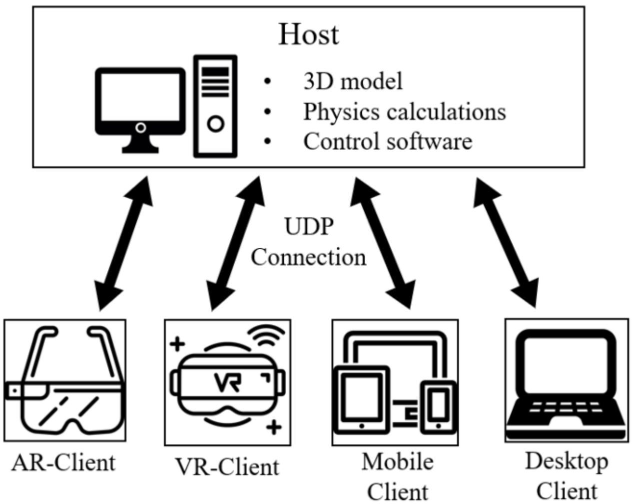


Figure 2 Architecture of the collaboration environment

5. Including devices and use case examples

5.1. Virtual Reality Headset

As already meantioned, VR does bring a lot of advantages to the engineering process by putting the user in a very natural perspective. Therefore it is great for inspection purposes or even just to showcase a product to potential customers. Figure 3 shows pictures of a VR setup with Head Mounted Devices (HMD's) and a powerwall in mono mode collaborating from different locations (University Albstadt & University Mannheim) to inspect the 3D Model of a assembly line in a multi-user collaboration meeting.

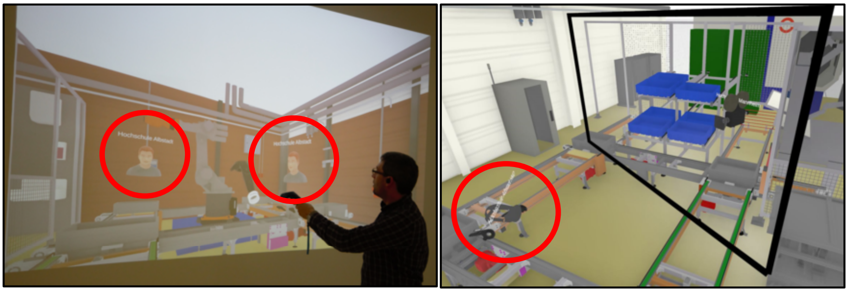


Figure 3 Collaborative Multi-User Session: HMD's at Albstadt University of Applied Sciences marked red, powerwall at Mannheim University of Applied Sciences represented with black square on the right

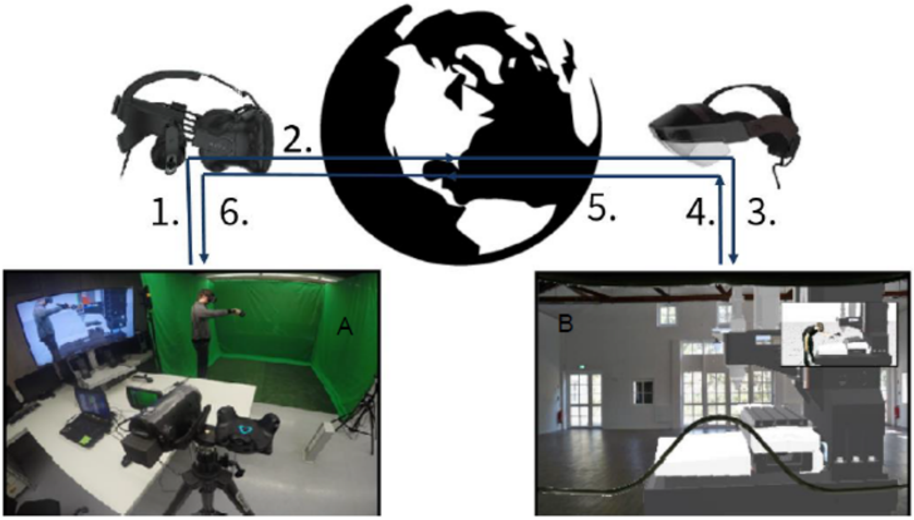
5.2. Augmented Reality Headset

In this usecase, a hybrid approach of AR and VR is used to optimise service cases. Service experts for complex systems are rare and global travelling to the service cases is time intense and costly. So the digital twin is used to showcase the work that needs to be done in a multi-user session. The expert of the system stays in the headoffice and joins the session with his VR headset. Using a greenbox and a dual lense camera, a video screen that shows the operater within the virtual environment is created.

Now a less experienced worker can join the session with his AR headset. He will see the realtime video stream of the expert as shown in Figure 4. The expert can give instructions and hints with visual support to the worker without physically being there.

5.3. Desktop PC

Because not everybody has access to a state-of the art VR oder AR headset, it is also necessary that users from desktop PC's or even mobile devices can join the session. So, in order to achieve this, a tool called „Virtual Reality Toolkit" is used to emulate the VR inputs to the software, even if the user joins from a desktop computer or a mobile device. The user does have the same possibilities to interact with the digital twin as if he would be using a VR device. Figure 5 shows an example screenshot of a multi-user session where one user joins via VR and the other via desktop PC. The user can choose if he wants to use a controller oder move his camera through the scene. However the emulated VR is not very intuitive and complicated to use. Therefore a dedicated user experience for desktop PC's and mobile devices needs to be developed.



1. generation of the video and audio signals for the stream to the AR headset.
2. transmission of the signals
3. displaying the stream as an AR object
4. generating the video and audio signals for the stream to the VR headset
5. transmission of the signals
6. displaying the stream in the VR headset-user's field of view.

Figure 4 VR/AR collaboration use case [5]

Figure 5 Screenshot of the emulated VR within the collaboration tool via desktop PC

6. Discussion

The use cases have shown, that the collaboration on a digital twin using different devices can be extremely helpful in many situations of the engineering process. It doesn't matter if it's just physical inspection of a model, kinematic studies, searching for problem solutions, ergonomic studies or testing the numerical control software. Digital twins have proven themselves as a very helpful feature. The possibility for all engineering disciplines to interact with a digital twin of a production system simultaneously is a very efficient way to improve transdisciplinary collaboration, because all involved engineers can discuss and test their ideas right at the digital twin in a virtual environment. Using immersive technologies also puts the engineers into a very natural perspective, that gives them a better understanding for the machines and the processes, which is especially helpful for less experienced engineers in a special subject. Especially computer scientists tend to have some difficulties to understand the function of the machines they are programming. Being able to interact with the digital twin and test the control programs without any risk of damaging a machine is a very helpful feature for these programmers. As [10] and [11] stated, the immersive technologies are helpful to detect design errors. And with the extended functionalities for the simulation of the numerical controls of the machines as well as the possibility to join a virtual conference from different devices, it results in a very good technical system for interdisciplinary collaboration.

However, depending on the needed level of accurateness of the digital twin, the creation can be extremely complicated and time comsuming. Also the simulation of numerical control units additionally to the 3D environment is computationally very challenging for a personal computer. So there will be strong limitations in the size of a production system, that consists of several machines with separate control units. An attempt to overcome these issues might be to migrate the simulation environment to a scalable server infrastructure. This might also save the limitations of the user capacity. If there is a large number of users in a collaborative session and there are data streams as well as interactions with the machine from every user, the system might crash. A dedicated managementsystem for users and what kind of interactions they are capable of, would also be useful, as it prevents that they might interfere with the interactions of other users. Therefore there is still a lot of potential for further development. Also the user concepts need to be precisely adjusted for each use case, as complicated user instructions tend to confuse less experienced users. Especially the user experience on desktop computers as well as on mobile devices need to be improved a lot, since there is no dedicated user concept, yet. The general engineering principle „as simple as possible, as complex as necessary" also applies in this area. Other topics to be developed is a voice chat for all devices and a video streaming function for desktop PC's and mobile devices, so the stream of their cameras can be used as avatars for virtual collaboration to make the collaboration experience more natural.

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