Bridging the Gap between Students and Laboratory Experiments

Max Hoffmann, Katharina Schuster, Daniel Schilberg, and Sabina Jeschke

Institute for Information Management in Mechanical Engineering
Center for Knowledge Management
RWTH Aachen University, Aachen, Germany
`max.hoffmann@ima.rwth-aachen.de`

Abstract. After having finished studies, graduates need to apply their knowledge to a new environment. In order to professionally prepare students for new situations, virtual reality (VR) simulators can be utilized. During our research, such a simulator is applied in order to enable the visit of remote laboratories, which are designed through advanced computer graphics in order to create simulated representations of real world environments. That way, it is our aim to facilitate the access to practical engineering laboratories.

Our goal is to enable a secure visit of elusive or dangerous places for students of technical studies. The first step towards the virtualization of engineering environments, e.g. a nuclear power plant, consists in the development of demonstrators. In the present paper, we describe the elaboration of an industry relevant demonstrator for the advanced teaching of engineering students. Within our approach, we use a virtual reality simulator that is called the “Virtual Theatre”.

Keywords: Virtual Reality, Virtual Theatre, Remote Laboratories, Immersion.

1 Introduction

In terms of modern teaching methods within engineering classes, various different approaches can be utilized to impart knowledge to students. There are traditional teaching techniques, which are still suitable for most of the knowledge transfer. These methods are carried out by the use of written texts or the spoken word. However, due to the increasing number of study paths as well as the specialization of particularly technical oriented classes, there is a need for the integration of new media into the curriculum of most students [1]. Thus, the visualization of educational content in order to explain theory more concrete and tangible has gained in importance. Not least because of the progress in computer science and graphical visualization, the capabilities of visualizing objects of interest within an artificially designed context have grown to an exhaustive amount. However, not only the visualization techniques have emerged, the way of distributing knowledge through teaching media has also grown. One major improvement in reaching students independently to their location are E-Learning Platforms [2]. These technical possibilities of sharing and representing contents open up new opportunities in teaching and learning for students.

R. Shumaker and S. Lackey (Eds.): VAMR 2014, Part II, LNCS 8526, pp. 39–50, 2014.

Thus, in nearly all courses of studies, new media have gained a high significance in the past decade. These new media are continuously replacing conventional media or in other words traditional, static teaching approaches using books and lecture notes. The new media are mostly based on methods of digital visualization [3], e.g. presentation applications like PowerPoint [4]. This switch from the traditional lecture speech to graphical representations have been performed, because this form of presentation enables focusing on the main points of educational content using illustrative representations and pictorial summaries [5]. Despite the positive [6], but also critical discussion about an overwhelming usage of PowerPoint [7–9] as primary teaching tool [10], the usage of presentation software in the classroom has grown constantly [11].

Applications like PowerPoint may be a far reaching advancement for most courses within university. However, even these IT-based teaching supports are limited to a certain kind of knowledge transfer. Especially practically oriented study paths like engineering courses have an urgent need for interaction possibilities. In these highly technical focused studies, the teaching personnel are facing more and more obstacles in imparting their knowledge tangible. Due to the advanced and complex technology level of the relevant applications [12], progressive methods have to be applied to fulfill the desired teaching goals. In order to make the problem based learning methodologies available [13], novel visualization techniques have to be carried out.

Studies of astronautics or nuclear research can serve as an incisive example for the need of innovative visualization capabilities. During astronomy studies, the teaching personnel will face insurmountable obstacles, if they want to impart practical knowledge about aerospace travelling to the students using theoretical approaches. In order to gain deep, experienced knowledge about real situations an astronaut has to face, realistic scenarios have to be carried out. This can for instance be performed by setting up expensive real-world demonstrators that facilitate practical experiences within aerospace travelling events, e.g. by making use of actual acceleration.

However, there is also a need for a visual representation of the situation. In order to fulfill the requirements of a holistic experience, these visualization techniques need to perform an immersive representation of the virtual world scenario. In this connection, the term immersion is defined according to Murray [14] as follow: “Immersion is a metaphorical term derived from the physical experience of being submerged in water. We seek the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air that takes over all of our attention, our whole perceptual apparatus.”

It is obvious that experience can only be impressive enough to impart experienced knowledge, if the simulation of a virtual situation has an immersive effect on the perception of the user. Our latest research on creating virtual world scenarios has shown that immersion has got a high impact on the learning behavior of students [15]. Following the idea of facilitating the study circumstances for students of astronautics, our first demonstrator was carried out in terms of a Mars scenario [16]. Using novel visualization techniques in connection with realistic physics engines, we have carried out a realistic representation of a plateau located on the red planet.

In our next research phase, we want to go further to increase the interaction capabilities with the virtual environment the user is experiencing. In terms of the Mars representation, there were already few interaction possibilities like triggering of object movements or the navigation of vehicles [16]. However, this sort of interaction is based on rather artificial commands than on natural movements with realistic consequences in the representation of the virtual world scenario.

Hence, in the present paper, we want to introduce a more grounded scenario, which is based on the aforementioned idea of enabling the visit of elusive or dangerous places like an atomic plant. Accordingly, our first step in realizing an overall scenario of a detailed environment like a power plant consists in the development of single laboratory environments. In this context, our aim is to focus especially on the interaction capabilities within this demonstrator.

This target is pursued by carrying out a virtual prototype of an actual laboratory environment, which can be accessed virtually and in real-time by a user in a virtual reality simulator. The realization of these demonstrators is also known as the creation of “remote laboratories”. In the present paper, we describe the development, optimization and testing of such a remote laboratory. After a brief introduction into the state-of-the-art of this comparatively new research field in chapter 2, our special Virtual Reality simulator, which is used to simulate virtual environments in an immersive way, is described in chapter 3. In chapter 4, the technical design of the remote laboratory including its information and communication infrastructure is presented. In the Conclusion and Outlook, the next steps in realizing the overall goal of a virtual representation of an engineering environment like an atomic plant are pointed out.

2 State of the Art

In the introduction, we concluded that innovative teaching methodologies have to be adopted to be capable of imparting experienced knowledge to students. Thus, virtual reality teaching and learning approaches will be examined in the following.

Nowadays, an exhaustive number of applications can be found that make use of immersive elements within real-world scenarios. However, the immersive character of all these applications is based on two characteristics of the simulation: The first one is the quality of the three-dimensional representation; the second one is the user’s identification with the avatar within the virtual world scenario.

The modeling quality of the three-dimensional representation of a virtual scenario is very important in order to be surrounded by a virtual reality that is realistic or even immersive. However, a high-quality graphical representation of the simulation is not sufficient for an intensive experience. Thus, according to Wolf and Perron [17], the following conditions have to be fulfilled in order to enable an immersive user experience within the scenario: “Three conditions create a sense of immersion in a virtual reality or 3-D computer game: The user’s expectation of the game or environment must match the environment’s conventions fairly closely. The user’s actions must have a non-trivial impact on the environment. The conventions of the world must be consistent, even if they don’t match those of the ‘metaspace’.”

The user's identification with virtual scenario is rather independent from the modeling of the environment. It is also depending on the user's empathy with the "avatar". Generally, an avatar is supposed to represent the user in a game or a virtual scenario. However, to fulfill its purposes according to the user's empathy, the avatar has to supply further characteristics. Accordingly, Bartle defines an avatar as follows: "An avatar is a player's representative in a world. [...] It does as it's told, it reports what happens to it, and it acts as a general conduit for the player and the world to interact. It may or may not have some graphical representation, it may or may not have a name. It refers to itself as a separate entity and communicates with the player."

There are already many technical solutions that are primarily focused on the creation of high-quality and complex three-dimensional environments, which are accurate to real-world scenarios in every detail. Flight Simulators, for example, provide vehicle tracking [18]. Thus, the flight virtual reality simulator is capable of tracking the locomotion of a flying vehicle within the virtual world, but does not take into account the head position of the user. Another VR simulator is the Omnimax Theater, which provides a large angle of view [19], but does not enable any tracking capabilities whatsoever. Head-tracked monitors were introduced by Codella et al. [20] and by Deering [21]. These special monitors provide an overall tracking system, but provide a rather limited angle of view [18]. The first attempt to create virtual reality in terms of a complete adjustment of the simulation to the user's position and head movements was introduced with the Boom Mounted Display by McDowall et al. [22]. However, these displays provided only poor resolutions and thus were not capable of a detailed graphical representation of the virtual environment [23].

In order to enable an extensive representation of the aimed remote laboratories, we are looking for representative scenarios that fit to immersive requirements using both a detailed graphical modeling as well as a realistic experience within the simulation. In this context, one highly advanced visualization technology was realized through the development of the Cave in 1991. In this context, the recursive acronym CAVE stands for Cave Automatic Virtual Environment [18] and was first mentioned in 1992 by Cruz-Neira [24]. Interestingly, the naming of the Cave is also inspired by Plato's Republic [25]. In this book, he "discusses inferring reality (ideal forms) form shadows (projections) on the cave wall" [18] within "The Smile of the Cave".

By making use of complex projection techniques combined with various projectors as well as six projection walls arranged in form of a cube, the developers of the Cave have redefined the standards in visualizing virtual reality scenarios. The Cave enables visualization techniques, which provide multi-screen stereo vision while reducing the effect of common tracking and system latency errors. Hence, in terms of resolution, color and flicker-free stereo vision the founders of the Cave have created a new level of immersion and virtual reality.

The Cave, which serves the ideal graphical representation of a virtual world, brings us further towards true Virtual Reality, which – according to Rheingold [26] – is described as an experience, in which a person is "surrounded by a three-dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it and reshape it." This enables various educational, but also industrial and technical applications. Hence, in the past the research already focused on the power of visualization in technical applications, e.g. for data visualizations purposes [27] or for the exploration and prototyping of complex systems like the visualization of air traffic simulation systems [28]. Furthermore, the Cave has also been used within medical or for other applications, which require annotations and labeling of objects, e.g. in teaching scenarios [29].

The founders of the Cave choose an even more specific definition of virtual reality: "A virtual reality system is one which provides real-time viewer-centered head-tracking perspective with a large angle of view, interactive control, and binocular display." [18] Cruz-Neira also mentions that – according to Bishop and Fuchs [30] – the competing term "virtual environment (VE)" has a "somewhat grander definition which also correctly encompasses touch, smell and sound." Hence, in order to gain a holistic VR experience, more interaction within the virtual environment is needed.

Though, it is our aim to turn Virtual Reality into a complete representation of a virtual environment by extending the needed interaction capabilities, which are, together with the according hardware, necessary to guarantee the immersion of the user into the virtual reality [31]. However, even the Cave has got restricted interaction capabilities as the user can only interact within the currently demonstrated perspectives. Furthermore, natural movement is very limited, as locomotion through the virtual environment is usually restricted to the currently shown spot of the scenario. Yet, natural movements including walking, running or even jumping through virtual reality are decisive for a highly immersive experience within the virtual environment.

This gap of limited interaction has to be filled by advanced technical devices without losing high-quality graphical representations of the virtual environment. Hence, within this publication, we introduce the Virtual Theatre, which combines the visualization and interaction technique mentioned before. The technical setup and the application of the Virtual Theatre in virtual scenarios are described in the next chapter.

3 The Virtual Theatre – Enabling Virtual Reality in Action

The Virtual Theatre was developed by the MSEAB Weibull Company [32] and was originally carried out for military training purposes. However, as discovered by Ewert et al. [33], the usage of the Virtual Theatre can also be enhanced to meet educational requirements for teaching purposes of engineering students. It consists of four basic elements: The centerpiece, which is referred to as the omnidirectional treadmill, represents the Virtual Theatre's unique characteristics. Besides this moving floor, the Virtual Theatre also consists of a Head Mounted Display, a tracking system and a cyber glove. The interaction of these various technical devices composes a virtual reality simulator that combines the advantages of all conventional attempts to create virtual reality in one setup. This setup will be described in the following.

The Head Mounted Display (HMD) represents the visual perception part of the Virtual Theatre. This technical device consists of two screens that are located in a sort of helmet and enable stereo vision. These two screens – one for each eye of the user – enable a three-dimensional representation of the virtual environment in the perception of the user. HMDs were first mentioned in Fisher [34] and Teitel [35] as devices that use motion in order to create VR. Hence, the characteristic of the HMD consists in the fact that it has a perpendicular aligned to the user and thus adjusts the representation of the virtual environment to him. Each display of the HMD provides a 70° stereoscopic field with an SXGA resolution in order to create a gapless graphical representation of the virtualized scenario [33]. For our specific setup, we are using the Head Mounted Display from zSight [36]. An internal sound system in the HMD enables an acoustic accompaniment for the visualization to complete the immersive scenario.

As already mentioned, the ground part of the Virtual Theatre is the omnidirectional treadmill. This omnidirectional floor represents the navigation component of the Virtual Theatre. The moving floor consists of rigid rollers with increasing circumferences and a common origo [33]. The rotation direction of the rollers is oriented to the middle point of the floor, where a circular static area is located. The rollers are driven by a belt drive system, which is connected to all polygons of the treadmill through a system of coupled shafts and thus ensures the kinematic synchronization of all parts of the moving floor. The omnidirectional treadmill is depicted in figure 1.

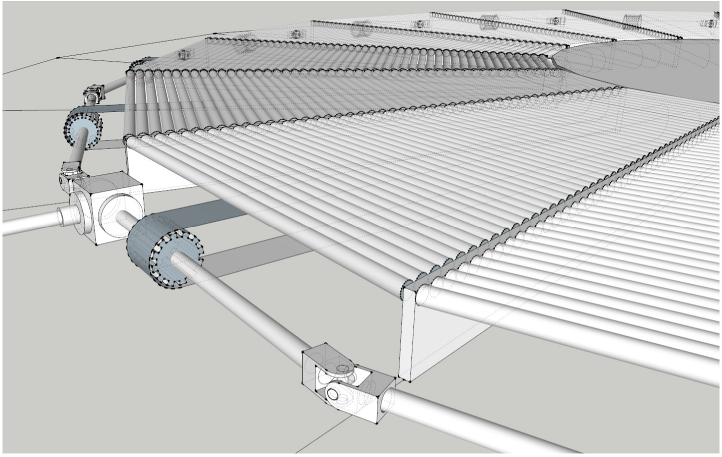

Fig. 1. Technical design of the Virtual Theatre's omnidirectional treadmill

On the central area that is shown in the upper right corner of figure 1, the user is able to stand without moving. As soon as he steps outside of this area, the rollers start moving and accelerate according to the distance of his position to the middle part. If the user returns to the middle area, the rotation of the rollers stops.

The tracking system of the Virtual Theatre is equipped with ten infrared cameras that are evenly distributed around the treadmill in 3 m above the floor. By recording the position of designated infrared markers attached to the HMD and the hand of the user, the system is capable of tracking the user's movements [33]. Due to the unsymmetrical arrangement of the infrared markers the tracking system is not only capable of calculating the position of the user, but is also capable of determining looking directions. That way, the three-dimensional representation of the virtual scenario can be adjusted according to the user's current head position and orientation. Furthermore, the infrared tracking system is used in order to adjust the rotation speed of the rollers no only according to the user’s distance from the middle point, but also according to the difference of these distances within a discrete time interval. Using these enhanced tracking techniques, the system can deal with situations, in which the user stands without moving while not being located in the middle of the omnidirectional floor.

The cyber glove ensures the tactile interaction capabilities. This special hand glove is equipped with 22 sensors, as indicated above, which are capable of determining the user’s hand position and gestures [33]. This enables the triggering of gesture based events like the grasping of objects. Additionally, special programmable gestures can be utilized in order to implement specific interaction commands.

After setting up the required hardware of the Virtual Theatre, the user can plunge into different scenarios and can be immersed by virtual reality. After the development of learning and interaction scenarios as described in [16], our main interest here is focused on the development of remote laboratories, which represent the first step towards the realization of a virtual factory. The development, testing and evaluation of our first “Remote Lab” are described in the next chapter.

4 Development of Remote Laboratories in the Virtual Theatre

The described setup of the Virtual Theatre can be used to immerse the user into a virtual reality scenario not only for demonstration purposes, but especially for the application of scenarios, in which a distinctive interaction between the user and the simulation is required. One of these applications consists in the realization of remote laboratories, which represent the first step towards the creation of real-world demonstrators like a factory or an atomic plant into virtual reality.

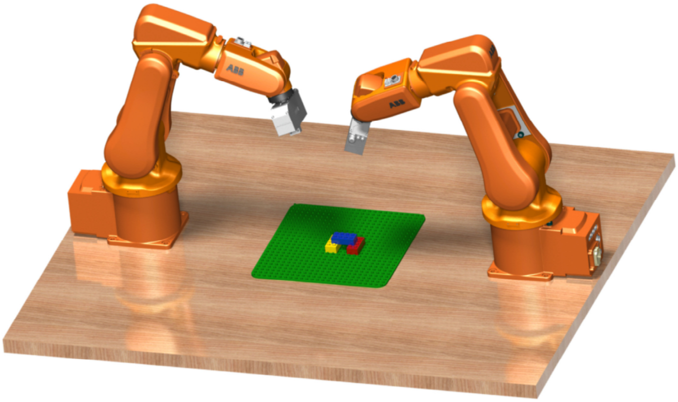

Fig. 2. Two cooperating ABB IRB 120 six-axis robots

The virtual remote laboratory described in this paper consists in a virtual representation of two cooperating robot arms that are setup within our laboratory environment (see figure 2). These robots are located on a table in such a way that they can perform tasks by executing collaborative actions. For our information and communication infrastructure setup, it doesn’t matter, if the robots are located in the same laboratory as our Virtual Theatre or in a distant respectively remote laboratory. In this context, our aim was to virtualize a virtual representation of the actual robot movements in the first step. In a second step, we want to control and to navigate the robots.

In order to visualize the movements of the robot arms in virtual reality, first, we had to design the three-dimensional models of the robots. The robot arms, which are installed within our laboratory setup are ABB IRB 120 six-axis robotic arms [37]. For the modeling purposes of the robots, we are using the 3-D optimization and rendering software Blender [38]. After modeling the single sections of the robot, which are connected by the joints of the six rotation axes, the full robot arm model had to be merged together using a bone structure. Using PhysX engine, the resulting mesh is capable of moving its joints in connection with the according bones in the same fashion as a real robot arm. This realistic modeling principally enables movements of the six-axis robot model in virtual reality according to the movements of the real robot. The virtual environment that contains the embedded robot arms is designed using the WorldViz Vizard Framework [39], a toolkit for setting up virtual reality scenarios.

After the creation of the virtual representation of the robots, an information and communication infrastructure had to be set up in order to enable the exchange of information between the real laboratory and the simulation. The concept of the intercommunication as well as its practical realization is depicted in figure 3.

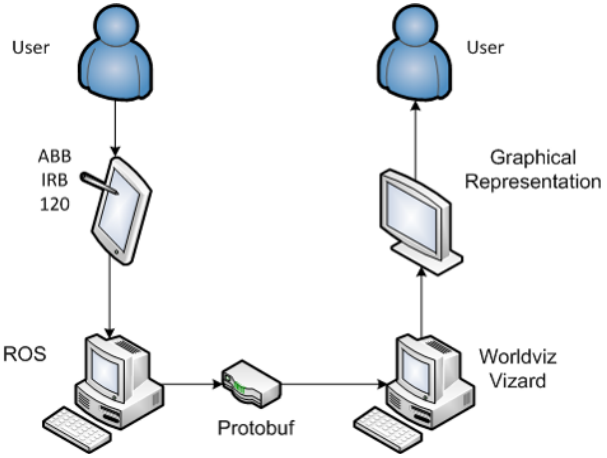

Fig. 3. Information and Communication Infrastructure of the remote laboratory setup

As shown in the figure, the hardware of the remote laboratory setup is connected through an internal network. On the left side of the figure, a user is demonstrated, who operates the movements of the real robot arms manually through a control interface of the ABB IRB 120 robots. This data is processed by a computer using Linux with embedded Robot Operating System (ROS). The interconnection between the real laboratory and the virtual remote laboratory demonstrator is realized using the Protocol Buffers (Protobuf) serialization method for structured data. This interface description language, which was developed by Google [40], is capable of exchanging data between different applications in a structured form.

After the robots' position data is sent through the network interface, the information is interpreted by the WorldViz Vizard engine to visualize the movements of the actual robots in virtual reality. After first test phases and a technical optimization of the network configuration, the offset time between the robot arm motion in reality and in virtual reality could be reduced to 0.2 seconds. Due to the communication design of the network infrastructure in terms of internet-based communication methods, this value would not increase significantly, if the remote laboratory would be located in a distant place, for example in another city or on the other side of the globe.

The second user, which is depicted in the right upper part of figure 3 and who is located in the Virtual Theatre, is immersed by the virtual reality scenario and can observe the positions and motions of the real robots in the virtual environment. In figure 4, the full setup of the real and the remote laboratory is illustrated.

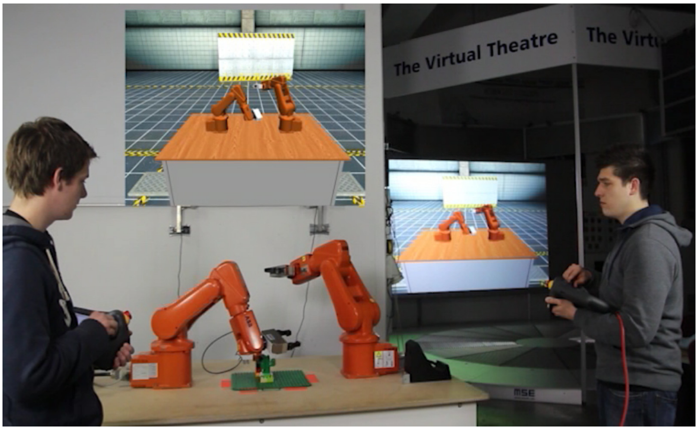

Fig. 4. Manual control of the robots and visual representation in the Virtual Theatre

In the foreground of the figure, two users are controlling the movements of the actual robots in the real laboratory using manual control panels. In the background on the right side of the picture, the virtual representation of the two ABB IRB 120 robot arms is depicted. The picture on the right side of the wall is generated using two digital projectors, which are capable of creating a 3-D realistic picture by overlapping the pictures of both projections. The picture depicted on top of the robot arms table is a representation of the picture the user in the VR simulator is actually seeing during the simulation. It was artificially inserted into figure 4 for demonstration purposes.

This virtual remote laboratory demonstrator shows impressively that it is already possible to create an interconnection between the real world and virtual reality.

5 Evaluation

The results of first evaluations within the test mode of our virtual remote laboratory demonstrator have shown that the immersive character of the virtual reality simulation has got a major impact on the learning behavior and especially on the motivation of the users. Within our test design, students were first encouraged to implemented specific movements of an ABB IRB 120 robot using the Python programming language. After this practical phase the students were divided into two groups.

The first group had the chance to watch a demonstration of the six axis robots carrying out a task using “LEGO” bricks. After seeing the actual movements of the robots within our laboratories, the students were fairly motivated to understand the way of automating the intelligent behavior of the two collaborating robots.

The second group of students had the possibility to take part in a remote laboratory experiment within the Virtual Theatre. After experiencing the robot movements in the simulated virtual environment performing the same task as the real world demonstrator, the students could observe the laboratory experiment they were just experiencing in the Virtual Theatre recorded on video. Their reaction on the video has shown that the immersion was more impressive than the observation of the actual robot’s movements performed by the other group. Accordingly, the students of the second comparison group were even more motivated after their walk through the virtual laboratory. The students of the second group were actually aiming at staying in the laboratory until they finished automating the same robot tasks they just saw in virtual reality.

6 Conclusion and Outlook

In this paper, we have described the development of a virtual reality demonstrator for the visualization of remote laboratories. Through the demonstrated visualization techniques in the Virtual Theatre, we have shown that it is possible to impart experienced knowledge to any student independent of his current location. This enables new possibilities of experience-based and problem-based learning. As one major goal of our research project “ELLI – Exzellentes Lehren und Lernen in den Ingenieurwissenschaften (Excellent Teaching and Learning within engineering science)”, which addresses this type of problem-based learning [13], the implemented demonstrator contributes to our aim of establishing advanced teaching methodologies. The visualization of real-world systems in virtual reality enables the training of problem-solving strategies within a virtual environment as well as on real objects at the same time.

The next steps of our research consist in advancing the existing demonstrator in terms of a bidirectional communication between the Virtual Theatre demonstrator and the remote laboratory. Through this bidirectional communication we want to enable a direct control of the real laboratory from the remote virtual reality demonstrator. First results in the testing phase of this bidirectional communication show that such a remote control will be realized in the near future. In order to enable a secure remote control of the remote laboratory, collision avoidance and other security systems for cooperating robots will be carried out and tested in the laboratory environment.

As the overall goal of our project consists in the development of virtual factories in order to enable the visit of an atomic plant or other elusive places, our research efforts will finally focus on the development of a detailed demonstrator for the realistic representation of an industrial environment.

Acknowledgment. This work was supported by the project ELLI (Excellent Teaching and Learning within engineering science) as part of the excellence initiative at RWTH Aachen University.

References

1. Kerres, M.: Mediendidaktik. Konzeption und Entwicklung mediengestützer Lernangebote. München (2012)
2. Handke, J., Schäfer, A.M.: E-Learning, E-Teaching and E-Assessment in der Hochschullehre. Eine Anleitung, München (2012)
3. Craig, R.J., Amernic, J.H.: PowerPoint Presentation Technology and the Dynamics of Teaching. Innovative Higher Education 31(3), 147–160 (2006)
4. Szabo, A., Hastings, N.: Using IT in the undergraduate classroom. Should we replace the blackboard with PowerPoint? Computer and Education 35 (2000)
5. Köhler, T., Kahnwald, N., Reitmaier, M.: Lehren und Lernen mit Multimedia und Internet. In: Batinic, B., Appel, M. (Hrsg.), Medienpsychologie, Heidelberg (2008)
6. Bartsch, R.A., Cobern, K.M.: Effectiveness of PowerPoint presentation in lectures. Computer and Education 41, 77–86 (2003)
7. Creed, T.: PowerPoint, No! Cyberspace, Yes. The Nat. Teach. & Learn. F. 6(4) (1997)
8. Cyphert, D.: The problems of PowerPoint. Visual aid or visual rhetoric? Business Communication Quarterly 67, 80–83 (2004)
9. Norvig, P.: PowerPoint: Shot with its own bullets. The Lancet 362, 343–344 (2003)
10. Simons, T.: Does PowerPoint make you stupid? Presentations 18(3) (2005)
11. Jones, A.M.: The use and abuse of PowerPoint in teaching and learning in the life sciences: A personal view. In: BEE-j 2 (2003)
12. André, E.: Was ist eigentlich Multimodale Mensch-Technik Interaktion? Anpassungen an den Faktor Mensch. In: Forschung und Lehre 21(01/2014) (2014)
13. Steffen, M., May, D., Deuse, J.: The Industrial Engineering Laboratory. Problem Based Learning in Industrial Eng. Education at TU Dortmund University. In: EDUCON (2012)
14. Murray, J.H.: Hamlet on the Holodeck: The Future of Narrative in Cyberspace, Cambridge (Mass.) (1997)
15. Schuster, K., Ewert, D., Johansson, D., Bach, U., Vossen, R., Jeschke, S.: Verbesserung der Lernerfahrung durch die Integration des Virtual Theatres in die Ingenieurausbildung. In: Tekkaya, A. E.; Jeschke, S.; Petermann, M.; May, D.; Friese, N.; Ernst, C.; Lenz, S.; Müller, K.; Schuster, K (Hrsg.). TeachING-LearnING.EU discussions. Aachen (2013)
16. Hoffmann, M., Schuster, K., Schilberg, D., Jeschke, S.: Next-Generation Teaching and Learning using the Virtual Theatre. In: 4th Global Conference on Experiential Learning in Virtual Worlds in print, Prague, Czech Republic (2014)
17. Wolf, M.J.P., Perron, B.: The video game theory reader, NY, London (2003)
18. Cruz-Neira, C., Sandin, D.J., DeFanti, T.A.: Surround-Screen Projection-based Virtual Reality. The Design and Implementation of the CAVE. In: SIGGRAPH 1993 Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques, pp. 135–142. ACM, New York (1993)
19. Max, N.: SIGGRAPH 1984 Call for Omnimax Films. Computer Graphics 16(4), 208–214 (1982)
20. Codella, C., Jalili, R., Koved, L., Lewis, B., Ling, D.T., Lipscomb, J.S., Rabenhorst, D., Wang, C.P., Norton, A., Sweeny, P., Turk, G.: Interactive simulation in a multi-person virtual world. In: ACM - Human Fact. in Comp. Syst. CHI 1992 Conf., pp. 329–334 (1992)

21. Deering, M.: High Resolution Virtual Reality. Com. Graph. 26(2), 195–201 (1992)
22. McDowall, I.E., Bolas, M., Pieper, S., Fisher, S.S., Humphries, J.: Implementation and Integration of a Counterbalanced CRT-based Stereoscopic Display for Interactive Viewpoint Control in Virtual Environment Applications. In: Proc. SPIE, vol. 1256(16) (1990)
23. Ellis, S.R.: What are virtual environments? IEEE Computer Graphics and Applications 14(1), 17–22 (1994)
24. Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R.V., Hart, J.C.: The CAVE: Audio Visual Experience Automatic Virtual Environment. Communications of the ACM 35(6), 64–72 (1992)
25. Plato: The Republic. Athens (375 B.C.)
26. Rheingold, H.: Virtual reality. New York (1991)
27. Nowke, C., Schmidt, M., van Albada, S.J., Eppler, J.M., Bakker, R., Diesrnann, M., Hentschel, B., Kuhlen, T.: VisNEST – Interactive analysis of neural activity data. In: 2013 IEEE Symposium on Biological Data Visualization (BioVis), pp. 65–72 (2013)
28. Pick, S., Wefers, F., Hentschel, B., Kuhlen, T.: Virtual air traffic system simulation – Aiding the communication of air traffic effects. In: 2013 IEEE on Virtual Reality (VR), pp. 133–134 (2013)
29. Pick, S., Hentschel, B., Wolter, M., Tedjo-Palczynski, I., Kuhlen, T.: Automated Positioning of Annotations in Immersive Virtual Environments. In: Proc. of the Joint Virtual Reality Conference of EuroVR - EGVE - VEC, pp. 1–8 (2010)
30. Bishop, G., Fuchs, H., et al.: Rsearch Directions in Virtual Environments. Computer Graphics 26(3), 153–177 (1992)
31. Johansson, D.: Convergence in Mixed Reality-Virtuality Environments: Facilitating Natural User Behavio, Schweden (2012)
32. MSEAB Weibull: `http://www.mseab.se/The-Virtual-Theatre.htm`
33. Ewert, D., Schuster, K., Johansson, D., Schilberg, D., Jeschke, S.: Intensifying learner's experience by incorporating the virtual theatre into engineering education. In: Proceedings of the 2013 IEEE Global Engineering Education Conference, EDUCON (2013)
34. Fisher, S.: The AMES Virtual Environment Workstation (VIEW). In: SIGGRAPH 1989 Course #29 Notes (1989)
35. Teitel, M.A.: The Eyephone: A Head-Mounted Stereo Display. In: Proc. SPIE, vol. 1256(20), pp. 168–171 (1990)
36. `http://sensics.com/products/head-mounted-displays/zsight-integrated-sxga-hmd/specifications/`
37. ABB, `http://new.abb.com/products/robotics/industrial-robots/irb-120` (last checked: January 27, 2014)
38. Blender, `http://www.blender.org/` (last checked: January 27, 2014)
39. WorldViz, `http://www.worldviz.com/products/vizard` (last checked: January 27, 2014)
40. Google, `http://code.google.com/p/protobuf/wiki/ThirdPartyAddOns` (last checked: January 27, 2014)