Dengzhe Ma
Jürgen Gausemeier
Xiumin Fan
Michael Grafe
Editors

Virtual Reality & Augmented Reality in Industry

上海交通大學出版社
SHANGHAI JIAO TONG UNIVERSITY PRESS

Springer

Dengzhe Ma
Jürgen Gausemeier
Xiumin Fan
Michael Grafe

Virtual Reality & Augmented Reality in Industry

The 2nd Sino-German Workshop

Dengzhe Ma
Jürgen Gausemeier
Xiumin Fan
Michael Grafe

Virtual Reality & Augmented Reality in Industry

The 2nd Sino-German Workshop

With 161 figures

上海交通大學出版社
SHANGHAI JIAO TONG UNIVERSITY PRESS

Springer

Editors

Dengzhe Ma
Dept. of Mechanical Engineering
Shanghai Jiao Tong University
200030, Shanghai, China
E-mail: dzma@sjtu.edu.cn

Xiumin Fan
Dept. of Mechanical Engineering
Shanghai Jiao Tong University
200030, Shanghai, China
E-mail: xmfan@sjtu.edu.cn

Jürgen Gausemeier
Heinz Nixdorf Institute
University of Paderborn
33102, Paderborn, Germany
E-mail: Jürgen.Gausemeier@ hni.uni-paderborn.de

Michael Grafe
Heinz Nixdorf Institute
University of Paderborn
33102, Paderborn, Germany
E-mail: Michael.Grafe@hni.uni-paderborn.de

ISBN 978–7–313–06426–4
Shanghai Jiao Tong University Press, Shanghai

ISBN 978–3–642–17375–2 e-ISBN 978–3–642–17376–9
Springer Heidebery Dordrecht London New York

Library of Congress Control Number: 2011920985

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Virtual reality and augmented reality (VR/AR) are key technologies for virtual engineering. They are the basis for functional virtual prototyping, which enables engineers to analyse the shape, form and functional behavior of future products in an immersive and interactive virtual environment. Applying these technologies greatly improves the communication in product design and production development: It helps to identify and avoid design errors in early stages of the development process, it reduces the number of physical prototypes and saves time and cost for enterprises. VR/AR are considered as valuable tools for improving and accelerating product and process development in many industrial applications. However, there are still many requirements unaddressed leaving considerable potential for further developing and improving VR/AR-based tools and methods.

This workshop intends to establish an open forum, dedicated to present and discuss innovative applications from industry and research from China and Germany, as well as to exchange experiences. It provides the opportunity to learn about state-of-the-art VR/AR applications in industry, and to directly experience new development and future trends of VR/AR technology.

This workshop is supported by the Department of High and New Technology Development and Industrialization of MOST (Ministry of Science and Technology of China), Deutsches Generalkonsulat Shanghai and Shanghai Science & Technology Committee. The purpose is to promote industrial application of VR/AR tools and methods in China, and to promote the science & technology exchange and cooperation between China and Germany. The publication of these proceedings is also supported by Shanghai JiaoTong University Press and Springer SBM.

We acknowledge all workshop sponsors, organizers and co-sponsors: Shanghai Jiao Tong University, Heinz Nixdorf Institute, University of Paderborn, Shanghai Automotive Industry Science and Technology Development Foundation, Manufacture Information Engineering of China Magazine, Shanghai Academy of Science & Technology, National Engineering Laboratory for Digital Shipbuilding (China), Shanghai Electric Group Co., Ltd. Central Academy, State Key Lab of CAD&CG, State Key Lab of Mechanical System and Vibration (China), Virtual Reality Professional

Committee (China Society of Image and Graphics), Shanghai Science & Technology Museum.

These proceedings can be used as reference for researchers and students in the fields of virtual reality and augmented reality and its application.

During the development of this proceeding, we have received invaluable input and support from the chapter authors, and support from System Simulation and Virtual Reality Group of Shanghai Key Lab of Advanced Manufacturing Environment. We are also grateful to the editors of SJTU press and Springer for their patience and professionalism during the editing process.

Dengzhe Ma
Jürgen Gausemeier
Xiumin Fan
Michael Grafe
Aug. 10th, 2009

Contents

Design and VR/AR-based Testing of Advanced Mechatronic Systems 1
Jürgen Gausemeier, Jan Berssenbrügge, Michael Grafe, Sascha Kahl and Helene Wassmann

From Space to the Forest and to Construction Sites: Virtual Testbeds Pave the Way for New Technologies 39
Jürgen Roßmann

Collaborative Virtual Assembly Operation Simulation and Its Application 55
Dengzhe Ma, Xijin Zhen, Yong Hu, Dianliang Wu, Xiumin Fan and Hongmin Zhu

Integration of Realtime Ray Tracing into Interactive Virtual Reality Systems 83
Hilko Hoffmann, Dmitri Rubinstein, Alexander Löffler,
Michael Repplinger and Philipp Slusallek

Instantreality — A Framework for Industrial Augmented and Virtual Reality Applications 91
Johannes Behr, Ulrich Bockholt and Dieter Fellner

Interactive Simulation Data Exploration in Virtual Environments 101
Marc Wolter, Thomas Beer, Philippe Cerfontaine, Bernd Hentschel and Torsten Kuhlen

Digital Olympic Museum and Sports Simulation 121
Zhigeng Pan, Ruwei Yun

Research on Key Technologies of Full Mission Navigation Simulation System 133
Yong Yin, Yicheng Jin, Hongxiang Ren, Xiufeng Zhang, Xiuwen Liu and Junsheng Ren

Virtual Assembly Environment for Product Design Evaluation and Workplace Planning 147
Xiumin Fan, Rundang Yang, Dianliang Wu and Dengzhe Ma

Numerically Controlled Virtual Models for Commissioning, Testing and Training 163
Marco Schumann, Michael Schenk and Eberhard Bluemel

Virtual Reality Boosting Automotive Development 171
Mangqin Jiang

Potentials of Innovative Technologies within the Scope of Complex Products and Services 181
Frank Thielemann

From Immersive Engineering to Selling and Teaching 191
Martin Zimmermann, Andreas Wierse

Index 199

Contributors

Thomas Beer, M. Sc.
Virtual Reality Group, RWTH Aachen University, Seffenter Weg 23, 52074
Aachen, Germany
E-mail: beer@vr.rwth-aachen.de

Johannes Behr, Dr.-Ing.
Fraunhofer-Institut für Graphische Datenverarbeitung, Fraunhofe-rstraße 5,
D-64283 Darmstadt, Germany
E-mail: Johannes.Behr@igd.fraunhofer.de

Jan Berssenbrügge, Dr.-Ing.
Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
E-mail: Jan.Berssenbruegge@hni.upb.de

Eberhard Bluemel, Dr. rer.nat.
Fraunhofer Institute for Factory Operation and Automation, Sandtorstrasse 22,
39106 Magdeburg, Germany
E-mail: eberhard.bluemel@iff.fraunhofer.de

Ulrich Bockholt, Dr.-Ing.
Fraunhofer-Institut für Graphische Datenverarbeitung, Fraunhofe- rstraße 5,
D-64283 Darmstadt, Germany
E-mail: Ulrich.Bockholt@igd.fraunhofer.de

Philippe Cerfontaine, Dipl.-Inform.
Virtual Reality Group, RWTH Aachen University, Seffenter Weg 23, 52074
Aachen, Germany
E-mail: cerfontaine@vr.rwth-aachen.de

Xiumin Fan, Prof. Dr.
CIM Research Institute, Shanghai Key Lab of Advanced Manufacturing Environment, Shanghai Jiao Tong University, HuaShan Road 1954, Shanghai 200030, China
E-mail: xmfan@sjtu.edu.cn

Dieter Fellner, Univ.-Prof. Dr. techn.
Fraunhofer-Institut für Graphische Datenverarbeitung, Fraunhofe-rstraße 5, D-64283 Darmstadt, Germany
E-mail: Dieter.Fellner@gris.tu-darmstadt.de

Jürgen Gausemeier, Prof. Dr.-Ing.
Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
E-mail: Juergen.Gausemeier@hni.upb.de

Michael Grafe, Dipl.-Ing.
Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
E-mail: Michael.Grafe@hni.upb.de

Bernd Hentschel, M. Sc.
Virtual Reality Group, RWTH Aachen University, Seffenter Weg 23, 52074 Aachen, Germany
E-mail: hentschel@vr.rwth-aachen.de

Hilko Hoffmann, Dr. sc. nat
German Research Center for Artificial Intelligence (DFKI), Stuhlsatzenhausweg 3, Campus D3.2, 66123 Saarbrücken, Germany
E-mail: Hilko. hoffmann@dfki.de

Yong Hu, B.Sc.
CIM Research Institute, Shanghai Jiao Tong University, HuaShan Road 1954, Shanghai 200030, China
E-mail: woodyong@sjtu.edu.cn

Mangqin Jiang, M. Sc.
Design Department, Pan Asia Technical Automotive Center (PATAC)
3999 Longdong Avenue, Pudong District, Shanghai,201201, China
E-mail: Manqing_Jiang@patac.com.cn

Yicheng Jin, Prof.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: jycdmu@dlmu. edu.cn

Sascha Kahl, Dipl.-Wirt.-Ing.
Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
E-mail: Sascha.Kahl@hni.upb.de

Torsten Kuhlen, Prof. Dr. rer. nat.
Virtual Reality Group, RWTH Aachen University, Seffenter Weg 23, 52074 Aachen, Germany
E-mail: kuhlen@vr.rwth-aachen.de

Xiuwen Liu, Dr.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: Liuxw@dlmu.edu. cn

Alexander Löffler, M. Sc.
Computer Graphics Group, Saarland University (UdS), Stuhlsatzenhausweg 3, Campus D3.2, 66123 Saarbrücken, Germany

Dengzhe Ma, Prof. Dr.-Ing.
CIM Research Institute, Shanghai Key Lab of Advanced Manufacturing Environment, Shanghai Jiao Tong University, HuaShan Road 1954, Shanghai 200030, China
E-mail: dzma@sjtu.edu.cn

Zhigeng Pan, Prof. Dr.
State Key Lab of CAD&CG, Zhejiang University, Hangzhou, 310027, China
E-mail: zgpan@cad.zju.edu.cn

Michael Repplinger, Dipl.-Inform
German Research Center for Artificial Intelligence (DFKI)
Stuhlsatzenhausweg 3, Campus D3.2, 66123 Saarbrücken, Germany
E-mail: michael.repplinger@dfki.de

Hongxiang Ren, Dr.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: dmu_rhx@163.com

Junsheng Ren, Dr.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: j.s.ren@126.com

Jürgen Roßmann, Prof. Dr.-Ing.
Institute of Man-Machine-Interaction, RWTH Aachen University, Ahornstr. 55, 52074 Aachen, Germany
E-mail: rossmann@mmi.rwth-aachen.de

Dmitri Rubinstein, Dipl.-Inform
German Research Center for Artificial Intelligence (DFKI)
Stuhlsatzenhausweg 3, Campus D3.2, 66123 Saarbrücken, Germany
E-mail: dmitri.rubinstein@dfki.de

Michael Schenk, Prof. Dr. rer.nat.
Fraunhofer Institute for Factory Operation and Automation, Sandtorstrasse 22, 39106 Magdeburg, Germany
E-mail: michael.schenk@iff.fraunhofer.de

Marco Schumann, Dipl.-Inform
Fraunhofer Institute for Factory Operation and Automation, Sandtorstrasse 22, 39106 Magdeburg, Germany
E-mail: marco.schumann@iff.fraunhofer.de

Philipp Slusallek, Prof.Dr.-Ing.
German Research Center for Artificial Intelligence (DFKI)
Stuhlsatzenhausweg 3, Campus D3.2, 66123 Saarbrücken, Germany
E-mail: philipp.slusallek@dfki.de

Frank Thielemann, Dr.-Ing.
UNITY AG, Lindberghring 1, 33142 Bueren, Germany
E-mail: frank.thielemann@unity.de

Helene Wassmann, Dipl.-Inform.
Heinz Nixdorf Institute, Fürstenallee 11, 33102 Paderborn, Germany
E-mail: Helene.Wassmann@hni.upb.de

Andreas Wierse, Dr.-Ing.
VISENSO GmbH, Nobelstraße 15, 70569 Stuttgart, Germany
E-mail: aw@visenso.de

Marc Wolter, Dipl.-Inform.
Virtual Reality Group, RWTH Aachen University, Seffenter Weg 23, 52074 Aachen, Germany
E-mail: wolter@vr.rwth-aachen.de

Dianliang Wu, Dr.
CIM Research Institute, Shanghai Key Lab of Advanced Manufacturing Environment, Shanghai Jiao Tong University, HuaShan Road 1954, Shanghai 200030, China
E-mail: dlwu@sjtu.edu.cn

Rundang Yang, Dr.
CIM Research Institute, Shanghai Jiao Tong University, HuaShan Road 1954, Shanghai 200030, China
E-mail: yrd@sjtu.edu.cn

Yong Yin, Prof. Dr.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: bushyin_dmu@263.net

Ruwei Yun, Associate Prof. Dr.
Edu-Game Center, Nanjing Normal University, Nanjing, 210097 China
E-mail: yunruwei@njnu.edu.cn

Martin Zimmermann
VISENSO GmbH, Nobelstraße 15, 70569 Stuttgart, Germany
E-mail: mz@visenso.de

Xiufeng Zhang, Dr.
Key Lab. of Marine Simulation & Control, Dalian Maritime University Dalian 116026, China
E-mail: zxfdmu@163.com

Xijin Zhen, Dr.
CIM Research Institute, Shanghai Jiao Tong University, Huashan Road 1954, Shanghai 200030, China
E-mail: zhenxj@sjtu.edu.cn

Hongmin Zhu, B.Sc.
CIM Research Institute, Shanghai Jiao Tong University, Huashan Road 1954, Shanghai 200030, China
E-mail: zhm_810304@sjtu.edu.cn

Design and VR/AR-based Testing of Advanced Mechatronic Systems

Jürgen Gausemeier, Jan Berssenbrügge, Michael Grafe, Sascha Kahl and Helene Wassmann
Heinz Nixdorf Institute, University of Paderborn, Germany

Abstract

Advanced mechatronic systems with inherent partial intelligence, so-called self-optimizing systems, react autonomously and flexibly on changing environmental conditions. Such systems are capable of learning and optimizing their behavior during operation. Their principle solution represents a significant milestone because it is the result of the conceptual design as well as the basis for the concretization of the system itself, which involves experts from several domains, such as mechanics, electrical engineering/electronics, control engineering and software engineering. Today, there is no established design methodology for the design of advanced mechatronic systems. This contribution presents a new specification technique for the conceptual design of advanced mechatronic systems along with a new approach to manage the development process of such systems. We use railway technology as a complex example to demonstrate, how to use this specification technique and to what extent it facilitates the development of future mechanical engineering systems. Based on selected virtual prototypes and test beds of the RailCab we demonstrate, how VR- and AR-based approaches for a visual analysis facilitate a targeted testing of the prototypes.

Keywords

Mechatronics, Self-Optimization, Design Methodology, Principle Solution, Targeted Testing, Virtual Prototype, Visual Analysis, Virtual / Augmented Reality

1 Virtual Prototyping in the Product Innovation Process

Products and manufacturing systems of mechanical engineering and its related industrial sectors like automotive engineering are getting more and more complex. Time-to-market is decreasing simultaneously. Under these circumstances the product innovation process is facing extraordinary challenges. Before we point out how to overcome these challenges, let us spend a brief look on the product innovation process.

The product innovation process starts from the idea of a product or business and leads to the successful product launch. It incorporates the areas of product planning, R&D and manufacturing process planning. The general work flow is shown in the figure. In practice, the product innovation process is iterative and comprises a number of cycles (see Fig. 1).

The first cycle characterizes the steps from finding the success potentials of the future to creating the promising product design, what we call the principle solution. There are four major tasks in this cycle:

- foresight
- product discovering
- business planning
- conceptual design

The aim of **foresight** is to recognize the potentials for future success, as well as the relevant business options. We use methods such as the scenario technique, Delphi studies and trend analysis.

The objective of **product discovering** is to find new product ideas. We apply in this phase creativity techniques such as the Lateral Thinking of de Bono or the well-known TRIZ.

Business planning is the final task in the cycle of strategic product planning. It initially deals with the business strategy, i.e. answering the question as to which market segments should be covered, when and how. The product strategy is then elaborated on this basis. This contains information:

- on setting out the product program
- on cost-effectively handling the large number of variants required by the market
- on the technologies used and
- on updating the program throughout the product lifecycle

Additionally, a business plan must be worked out to make sure an attractive return on investment can be achieved.

This first cycle is also concerned with the **conceptual design,** although this area of activity is actually assigned to product development in the strict sense. The result of the conceptual design is the principle solution. It is, for example, required to determine the manufacturing costs needed in the business plan. That is the reason why there is a close interaction between strategic product planning and product design linked by conceptual design. Conceptual design is the starting point for the next cycle.

This second cycle corresponds to the established understanding of product development. The essential point here is the refinement of the cross-domain principle solution by the domain experts involved, such as mechanical engineering, control technology, electronics and software engineering. The results elaborated by the domains in this cycle must be integrated into an encompassing product specification. This specification has to be verified in the light of the requirements given by the first cycle.

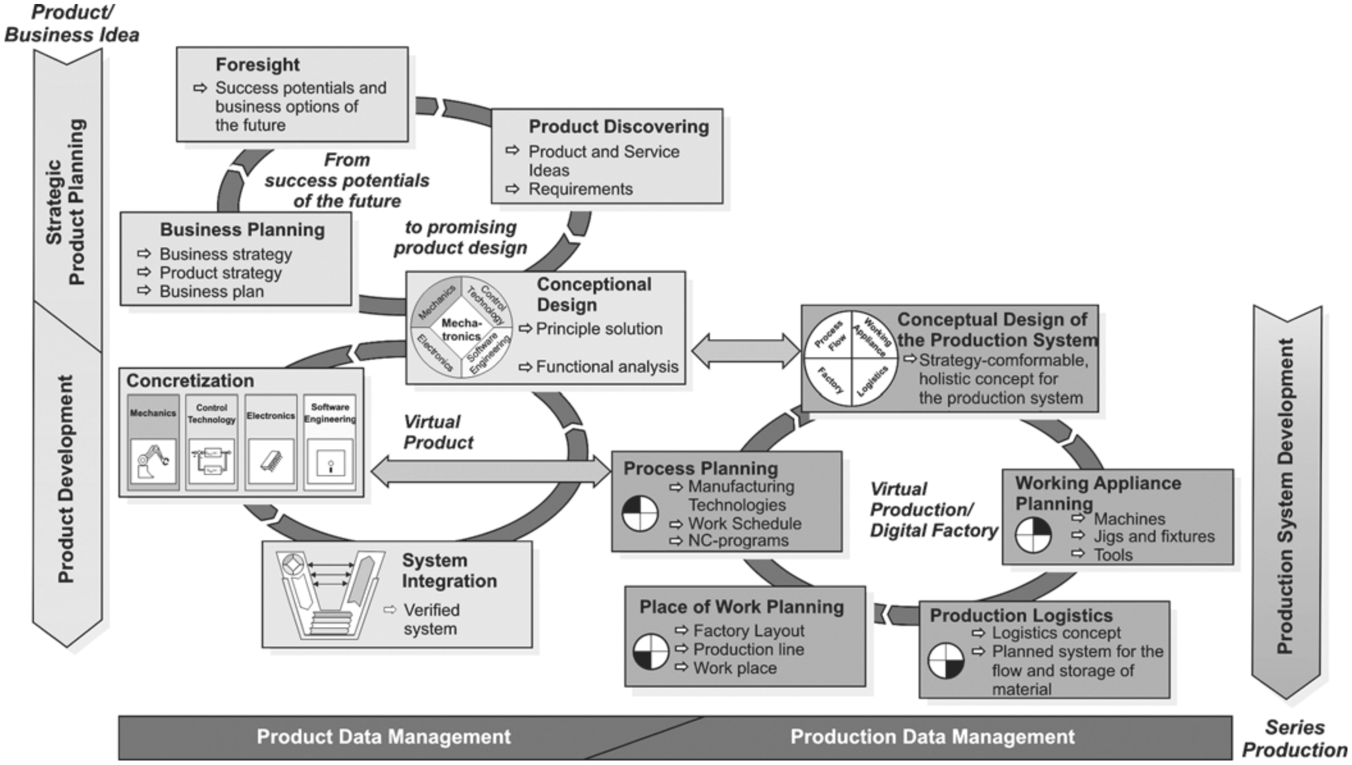


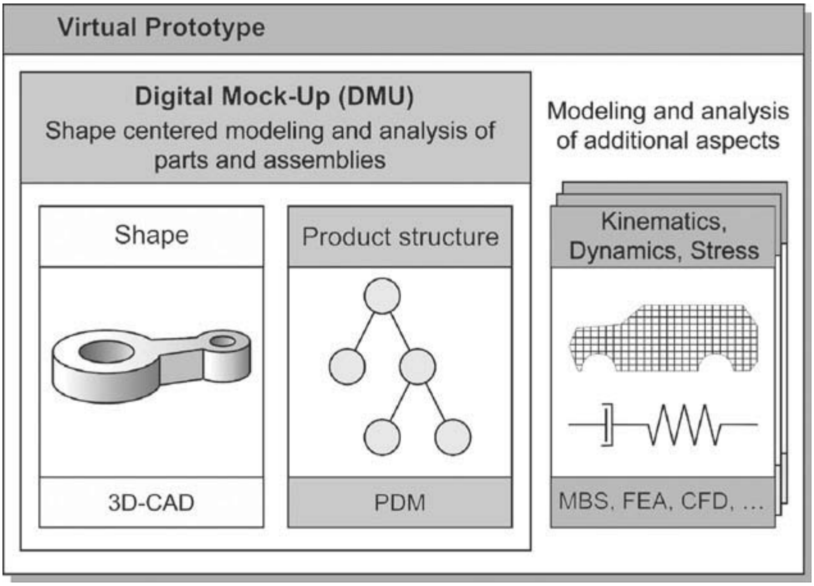
Fig. 1 The product development process as a sequence of cycles [1]

This is done in the product integration phase.

The third and last cycle focuses on manufacturing process development and the optimization of the product design with respect to manufacturing.

The second and the third cycle Product Development and Development of the corresponding manufacturing process are decisively driven by information technology. A key element is Virtual Prototyping. It means to build and analyze computer models of products and production systems being developed in order to reduce time- and cost-intensive manufacturing and testing of prototypes to a minimum. Simulation is another term for experimenting with such computer models. When we model products in the computer, we talk about the virtual product; in analogy we use the buzzwords virtual production or digital factory when we model the manufacturing system.

A perfect virtual prototype represents all aspects of a product (see Fig. 2). 3D-CAD systems are basically used to model the shape of parts. The breakdown of the product to its parts and assemblies is represented by the product structure. Therefore, it is necessary to set up a Product Data Management (PDM). The shape of individual parts in conjunction with product structure is used to develop a shape-based design of the product, what we call Digital Mock Up (DMU). It represents the spatial composition of all parts and assemblies of the product. A DMU can be used to carry out experiments such as clash detection, checking assembly and disassembly sequences. This is all based on the shape of the technical system. To analyze the behavior, we need to consider additional aspects offered by a virtual prototype.



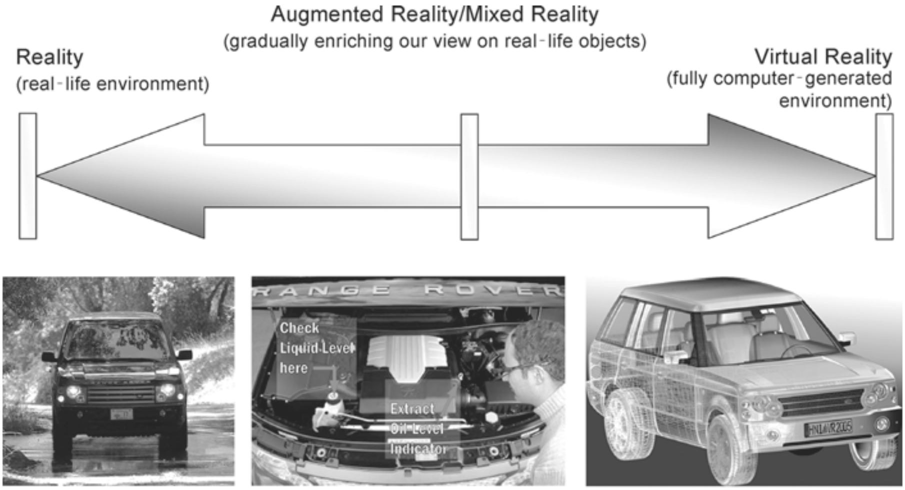
PDM: Product Data Management
MBS: Multi Body Simulation
FEA: Finite Element Analysis
CFD: Computational Fluid Dynamics

Fig. 2 From solid modeling to virtual prototyping [2]

As Fig. 2 illustrates, we consider a virtual prototype as an extension to DMU since it covers additional aspects such as kinematics, dynamics, and stress. A virtual prototype represents not only shape but also functional features and behaviors. Although, virtual prototyping cannot completely replace experiments with real prototypes, it scientifically contributes to a shorter time-to-market and less development costs even for more complex products and production systems.

2 Virtual Reality (VR) and Augmented Reality (AR)

Virtual Reality (VR) and Augmented Reality (AR) are key technologies of Virtual Prototyping. They are easy-to-understand user interfaces to a virtual design space and facilitate an interactive exploration of the functionality of a new product.



The Real Thing!

AR-supported engine maintenence: Mixing camera picture and CG-objects

VR-Model,typically derived from CAD-data

Fig. 3 From real-life to virtual reality

VR means a fully computer generated, three-dimensional environment, in which the engineer can interact with and manipulate a realistic representation of the product in real time. AR goes one step beyond: in contrast to VR, AR enriches the user's view on the real world with virtual objects, which are placed at right time and position regarding the user's perspective. Figure 3 shows an example for the transition from Reality (the real Range Rover) to AR (mixing the real engine with computer generated object for maintenance purposes) to VR (a realistic 3D-modell of the car). In details, VR technology can be characterized by the following main aspects:

Firstly, VR stands for a **realistic rendering** of the product appearance (material, surface, colors) and behavior. Secondly, VR makes use of **advanced display**

technologies that allow the engineers to experience the virtual prototype like a real one. Figure 4 (top left) shows some typical VR-display systems: Head mounted displays (HMD) with small LCD-monitors in front of the eyes. They allow a spatial view on the virtual prototype, but offer less image quality and wearing comfort.

In consequence, today most industrial VR applications use projection-based display systems that consist of several projections in different configurations. The typical configurations of such systems include PowerWall (Fig. 4, lower half) for group presentation or CAVE (Fig. 4, top right) for more spatial immersion of the users.

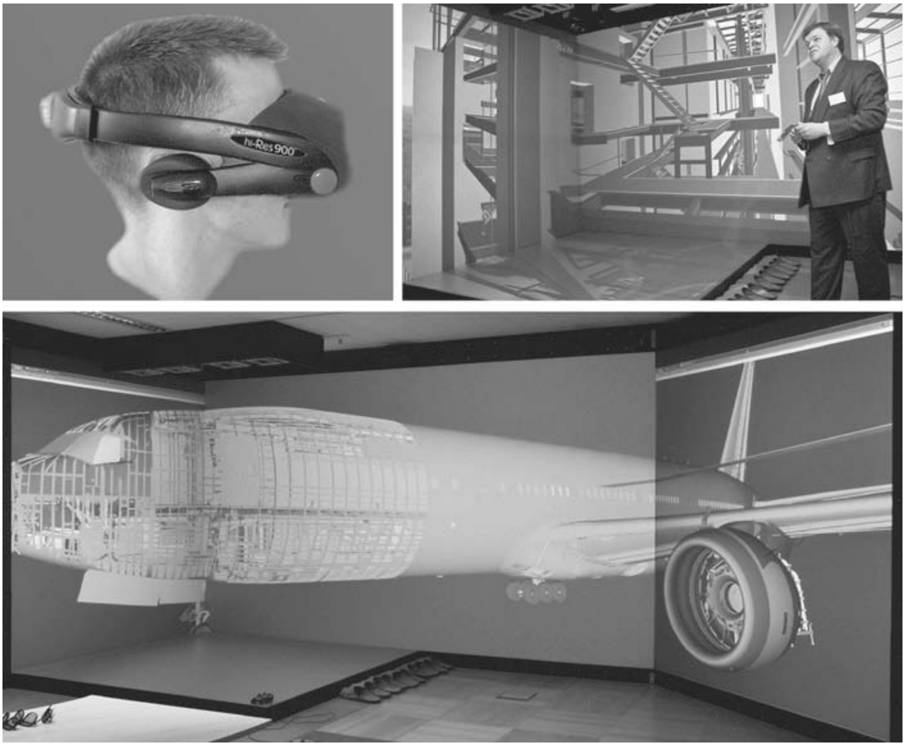


Fig. 4 Sample display devices used for VR applications: HiRes900 HMD (top left, source: Daeyang), CAVE application (top right, source: HD-Visualisation Center, HNI) and powerwall system at HNI HD-Visualisation Center (lower half, source for visualized dataset: Boeing)

In VR, the engineer has to navigate in 3D-space and to manipulate 3D-objects. Therefore, **VR-specific devices for spatial interaction** like 3D-Mouse, 3D-Wands or gloves are needed. By the help of 3D-position tracking systems, the VR system knows the position and orientation of the user in the virtual environment and is able to interpret the navigation and manipulation commands.

The main challenge of AR technology is the **context-sensitive mixture of real world elements and computer generated objects in the user's field of view**. Therefore, an exact position tracking of the user inside the real world is needed in realtime. Based on this information, the AR-system determines the virtual objects to be shown, their size and position in the user's field of view.

Today there are two different approaches to display the mixed image of real and virtual objects: "Video-see-through" display devices have integrated miniature video cameras. The user sees a real-time video stream of his real environment, which is enriched with computer-generated objects. Figure 5 (top right) shows a video-see-through HMD published by Canon in 2002 and its application in car door assembly (see Fig. 5, top left).

Fig. 5 Sample display devices and AR applications: AR-system for vehicle assembly (top left, source: Brose), video-see-through HMD (top right, source: Canon), automotive head-up display (lower left, source: AUDI) and optical-see-through glasses (lower right, source: Zeiss)

In Fig. 5 (lower left), we see an example of "optical-see-through" display in a car. The computer generated objects are directly projected in the front window. Here, the complex and time-consuming video processing is not necessary. Figure 5 (lower right) shows a high resolution optical-see-through HMD from Zeiss.

3 Up-to-date Applications of VR and AR in Industry

In recent years, VR technology has successfully made its way from research institutes into industrial practice. VR today is a key technology in industry, e.g. in product development, plant engineering and service. It facilitates the engineer's understanding of complex design concepts and allows more efficient interaction between the engineer and the computer. This saves time and money and finally enhances product quality. Augmented Reality is still at the beginning of its industrial employment, however first joint research projects with partners from industry show the great benefit of this fascinating technology.

The following projects of the Heinz Nixdorf Institut give a survey about how VR and AR technology could be applied in the product innovation process.

3.1 Composing Mechatronic Systems in VR

The complexity of modern mechatronic systems and the necessity to efficiently analyze and explore their large number of potential configurations and behavior patterns ask for new development methods and tools. We developed a virtual prototyping environment[1], which allows the engineers to interactively compose mechatronic prototypes in the virtual world [3,4]. The design approach we used is based on the combined effects of interconnected system elements, also referred to as "solution elements", like sensors, actuators, and mechanical parts as well as Mechatronic Function Modules (MFM).

During the design in the virtual environment, the system composition is executed in a synthesis and analysis cycle (Fig. 6). In the first step, the system synthesis, the engineer interactively arranges the assembly structure. Therefore, he uses 3D-models of solution elements from a construction library. In parallel, the active structure of the assembled system will be automatically deduced by the design system. The active

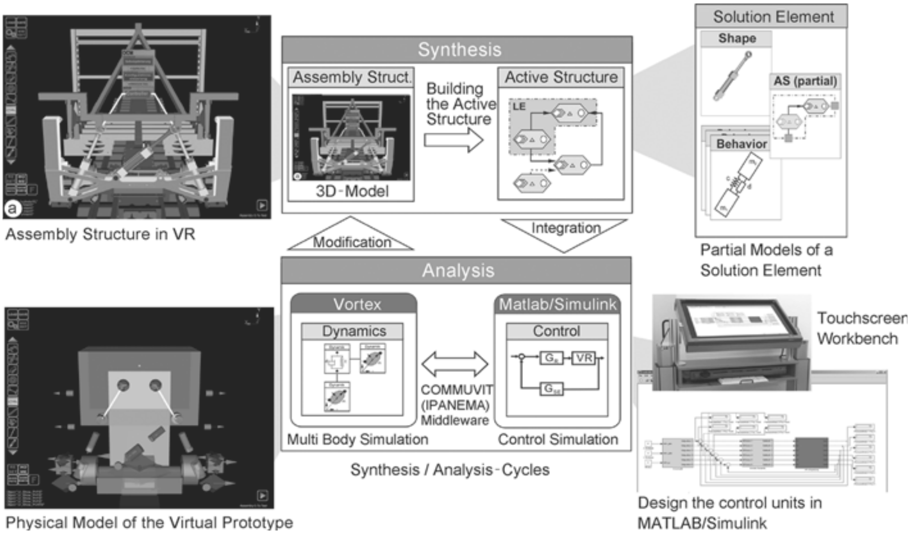


Fig. 6 Synthesis / analysis cycle in the composition of mechatronic systems

---

[1] This research was conducted as a part of the Collaborative Research Center 614 "Self-Optimizing Concepts and Structures in Mechanical Engineering", which is supported by German Research Foundation.