Visualization in Human-Centered Virtual Factories

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Abstract

In a manufacturing system (MS), a wide range of human activities are applied in production processes. The human factor plays a core role and should be incorporated into the design, planning and decision making processes. In this work we describe different definitions, developments and existing concepts of a Virtual Factory (VF) and discuss VFs from the human oriented point of view. Furthermore, we analyze the potential need and use of visualization methods in VF study and propose a human-centered VF concept. Following this concept we introduce an example implementation and describe how our model facilitates the decision making and design process in MS. In addition, we show an example of a noise analysis of working environment, which is based on our virtual factory model.

Keywords and phrases Visualization, Virtual Reality, Virtual Factory, Sound Simulation

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1 Introduction

Rapid development of theories and concepts of the Virtual Factory (VF) in the last two decades significantly improved the design and analysis of the manufacturing system (MS) in industry. Human factors play a key role in MSs in particular when facing challenges such as faster product changes and shorter planning time. However, in existing VF designs not enough attention is paid to human factors. People have to perform increasingly complex operation processes to ensure the functioning of the MS. Even if modern machining centers together with other support systems are capable of performing, for example, very precise and fast automatic cutting processes, failures are often caused by incorrect configuration and/or operation by the workers. Therefore, new methods for training employees need to be developed to enable machine operators to fulfill these tasks.

In manufacturing, employees are stressed by different factors in their working environment, such as, noise, air pollution, heat, or low/high levels of humidity. To protect health and safety of workers in manufacturing industry, manufacturers have to follow strict laws and guidelines, e.g. in Germany, the Federal Ministry of Labor and Social Affairs (BMAS) limits noise and vibration levels within Germany's Occupational Safety Law (Arbeitssicherheitsgesetz - ASiG), German ordinance (LärmVibrationsArbSchV) and other additional legal guidelines. Thus, the working environment needs to be analyzed during the design and planning process with regard to occupational health and safety aspects. Dedicated methods and tools are needed for measurement, simulation, analysis, evaluation, visualization, and optimization of activities related to MSs.

Large companies are already adopting more and more new technologies into their MSs. Due to high costs and long start-up time, for small and medium enterprises (SMEs) it is still difficult to obtain enough know-how to perform various instruments to enhance the human factor in MS [4, 18]. There is a need for a cost efficient and easy to customize VF framework to enable manufacturing SMEs to view, analyze, inspect and optimize facility layout during the planning process and to train their workers [17].

Currently available visualization techniques aid in understanding and analysis of complex simulations or measurements and facilitate presentation and communication of them[25, 26]. The significance of the visualization of manufacturing systems has been discussed in [16, 12].

In our work we review existing human-centered VF concepts and discuss the potential use of visualization methods in this context. The remainder of our paper is organized as follows. In the next section we define the term VF, discuss existing concepts and introduce the human-centered view in VF. In section 3 we outline our human-centered VF concept and visualization framework. In section 4 we show noise analysis example in a factory model, before we conclude our work in section 5.

2 Related work

In literature, a large range of VF definitions and classifications of VF concepts have been proposed. For example, Jain et al. [10] classified the various VF definitions into four categories: i) representation of all major aspects of a factory, ii) a virtual organization, iii) the Virtual Reality (VR) representation of a factory, and iv) an emulation facility for production activity in a factory. Before we discuss the human-centered VF concept and our example implementation in section 3, we provide in the following a brief overview of various VF definition with special regard to the human-centered perspective.

2.1 The Virtual Factory concept

In the narrow sense, VF is a rebuilt model of a real factory. It is basically a 3D geometric model of facilities and machines, consisting of primitive shapes, colors, and textures etc., usually structured in parent-child hierarchies. Furthermore, a VF represents all activities and aspects in the real factory. Every single production activity is modeled and simulated to support or test operational, tactical and strategic decisions. In this case, a VF provides a basic virtual environment for simulation and visualization. Kelsick and Vance [11] define and develop a VF as “a visual, three-dimensional space in which to explore the effect of various product mixes, inspection schedules, and worker experience on productivity”. Bodner and Reveliotis [3] define a VF as “an environment for use as a high fidelity test bed for manufacturing system design and control”. Souza et al. [13] build a VF as a VR environment for modeling and simulation of a factory where both the layout design and the production process are taken into account.

In its broad sense, VF is a comprehensive concept which includes various instruments and can be studied from two views. One point of view is based on the technical aspect, in terms of computer aided modeling, simulation and visualization [23]. In this case VF can be understood as a general digital support system, which is a powerful tool in research and development areas as well as in production or controlling areas of manufacturing, especially in the planning phase. VF systems contain application software for possible activities in

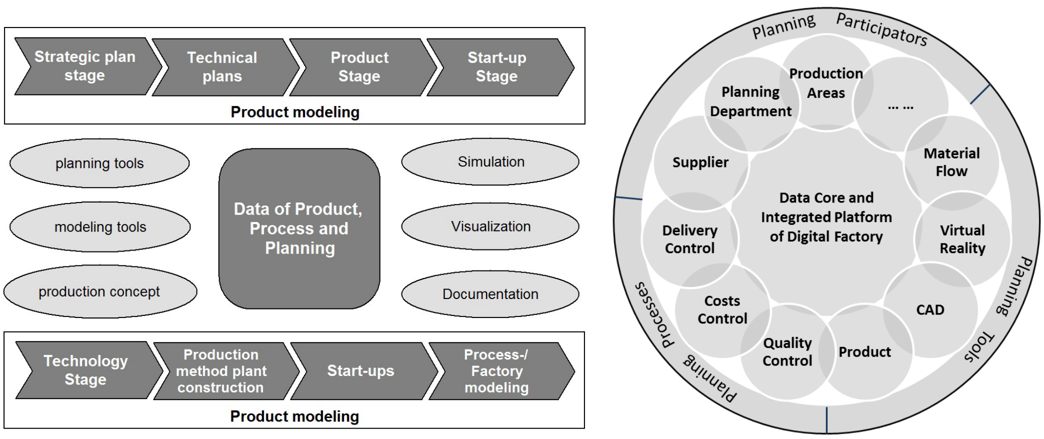
MSs. Banerjee and Zetu [1] describe virtual factories as "a distributed, integrated, computer-based composite model or a total manufacturing environment, incorporating all the tasks and resources necessary to accomplish the operation of designing, producing, and delivering a product". In [25], Zhong and Shirinzadeh built a VF framework using an integrated methodology. Their framework enables the direct integration of discrete event simulations with 3D animation.

Another point of view is the perspective of the management and organization. VFs are understood as "a co-operation of legal and economic independent enterprises (or units of them) with the aim to set up together the necessary preconditions to be able to identify opportunities in the markets and to grasp them quickly and efficiently together with partner" [24]. Schuh et al. [9] use a similar definition of VFs and discuss an application and branch customized VF concept. Upton and McAfee [20] emphasize VFs as collaborative and internetworked environments enabling several partners to share information and tools about a product, process or project.

In our work we define a VF as follows: a VF is a virtual environment, which contains a geometric model of the factory, machines and humans. In addition, measurement, simulation, visualization, documentation, VR, evaluation etc. are included as well. Furthermore, the feedback or modified information from a VF is coupled with real activities in MS. For example, material flow simulation in production processes, finite element simulation (FEM) of machining processes, collision detection simulation for layout planning or dynamic simulation for product design provide supporting information to build new or to modify existing factory models.

2.2 Concept of a Digital Factory

The established concept of the Digital Factory (DF) is closely related to the VF concept and is often used synonymously to VF in the literature [6]. The Association of German Engineers (VDI), defines in guideline 4499, DF as the generic term for a comprehensive network of digital models, methods and tools - including the simulation and 3D/VR-visualization for analysis of different processes in a factory.



(a) DF methods and tools, adapted from [12] **(b)** DF modules, adapted from [22]

Figure 1 DF methods, tools and modules

Kühn [12] uses the VDI definition and describes several DF methods and tools (see Figure 1a) such as planning, modeling, production, simulation, and visualization, to support product, process, and factory modeling. These methods and tools share the data in the DF through a consistent data management system. The goal is the holistic planning, evaluation and ongoing improvement of all essential processes and resources of the factory. Zülch [26] defines a DF as a set of comprehensive technical and organizational tools for design, visualization and running of future production system in a digital model. Westkämper and Zahn [22] describe DFs as a development method and a platform that uses centered data and integrates many different tools and concepts. The authors discuss different modules of DF (see Figure 1b), e.g.: production, material flow, planning, supplier, product design, etc. as well as their tasks in a DF. Furthermore, they emphasize the significance of DF for factory and production planning.

Nylund et al. [14] summarize some general characteristics of VF and DF as follows: i) "an emerging and integrated approach to improve product and production engineering processes and technology", ii) "computer-aided tools, such as modelling and simulation, for planning and analyzing real manufacturing processes" and iii) "a framework for new technologies, including the collection of systems and methods." There is no need to distinguish the VF and DF in this field regarding MSs. In this paper we do not differentiate between DF and VF; meaning that DF is equal to VF.

2.3 Human-centered perspective

Most MSs are technology, not human, driven. The typical technology driven perspective is as follows: science finds, industry applies, man confirms. In contrast, the human-centered perspective can be described as: people propose, science studies, technology confirms. As shown in Figure 2, in the human-centered view, the human factor is considered as one of the most important pillars among technology and system. More information about human-centered systems can be found in [19].

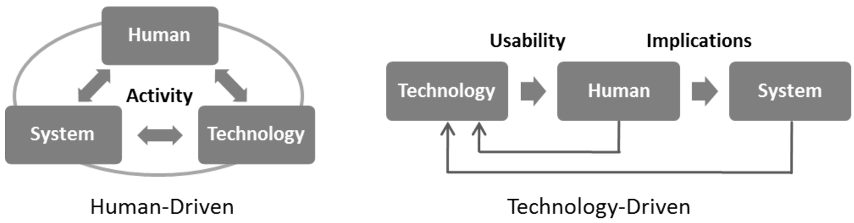


Figure 2 Human-Driven vs. Technology-Driven, adapted from [7]

Product design, factory layout design and production processes are usually accounted for VF concepts, for example in [23, 5, 25], while human factors are considered less important. Even if in real factories, many efforts are done to consider human factor. But its integration into VF is not sufficient. In VDI 3633 several criteria are studied from ergonomics point of view such as the staff work load regarding capacity demand, the degree of overstrain and fatigue, and the influence of the qualification of employees on their human error probability. This provides a starting point for a broad study field.

In the research project DiFac (Digital Factory for Human Oriented Production System) [18], Sacco et al. describe ergonomics, presence, and collaboration in an industrial virtual environment. Presence contains function components such as training, product development, and factory design. Zülch classifies ergonomics study into micro- and macro-ergonomics

[26]. The micro-ergonomic study analyzes human posture and body motion during tasks execution, whereas in macro-ergonomics, the stress and strain of the tasks to be accomplished by the worker are investigated. Furthermore, human-centered criteria are used to investigate and evaluate the working conditions. In [21], Viganò et al. introduce the GIOVE VF toolkit, which enables human oriented planning. They conclude that the major advantages of human oriented VF are increased efficiency of collaboration, reduced complexity of communication, reduced factory design time, and better working conditions.

In our human-centered VF concept we focus on training in the presence study and on macro-ergonomics in the ergonomics analysis. In the next section we describe the VF concept based on the above discussed human-centered point of view. In addition, we present an implementation example of our visualization-based framework.

3 Human-centered VF concept

Current work aims to use a low-cost solution to enable SMEs to visualize and analyze the information obtained from product lines or even the whole manufacturing system. Typical needs of SMEs in this context include enhancing the understanding of processes, reducing the potential risks of working environment in earlier planning level, and supporting the decision making. In many cases, these needs depend on what kind of products are produced, what kind of manufacturing methods are used, or what key issues have to be worried about. For example, thermo forming companies need to visualize air temperature, whereas for other machining enterprises, noise analysis may be more important. Hence, there is a need for a VF concept that can adapt to different fields and so its implementation has the following requirements: open architecture, flexibility, expandability, high compatibility and transparent development models.

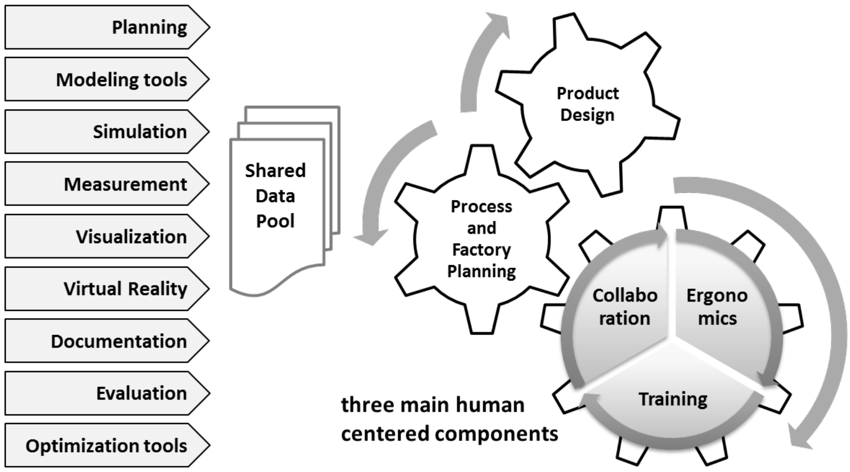


Figure 3 Human-centered study in VF

Figure 3 shows the structure of our human-centered VF concept. In our integrated VFs there are three main driving gears: i) human factor, ii) process and factory planning, and iii) product design. The three gears are interconnected. Thus, training, ergonomics and collaboration aspects are taken into account as are the other two major processes. A shared data pool enables the exchange of information between an extensive range of tools such as planning, modeling, simulation, production concept, visualization and others. As a result of the complexity of the processes in MSs, the information obtained from the above mentioned tools is also complex, not intuitive and difficult to understand. Visualization serves as a key method to help analysts to verify models, understand simulation results and to communicate them to non-technical audience [15, 16, 12].

The outline of our scene-graph-based visualization framework is shown in Figure 4. The workflow begins with modeling or simulation software. In addition to the geometric model, measured and/or simulated data is collected, selected and integrated into the scene. OpenSceneGraph (OSG)[1] is used for graphical rendering and interactive scene building. We made this choice because OSG is a cross-platform graphics toolkit, which is widely used in different application areas running on a desktop computer as well as on VR system. Individual VF modules are developed on top of this flexible scene-graph-based model which helps us to fulfill individual user requirements and need.

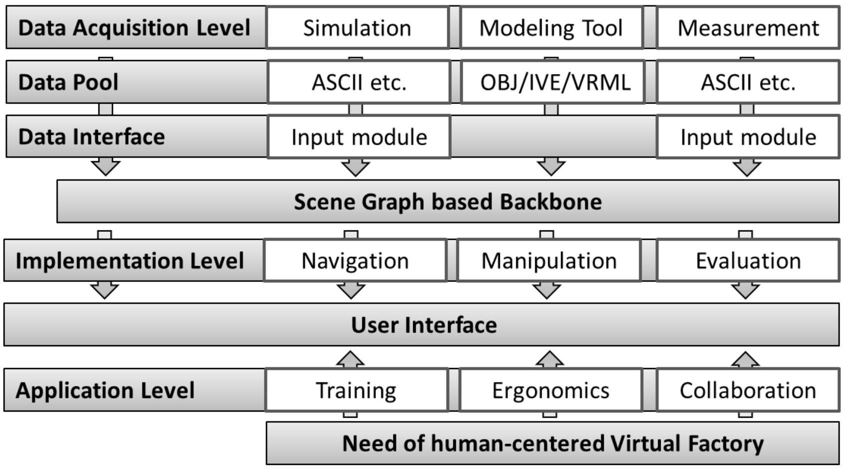


Figure 4 Framework structure

For example a scene graph can be modeled in 3DSMax[2] and exported as OSG native format (IVE), Alias Wavefront OBJ, or VRML2 (Virtual Reality Modeling Language) standard, in which all objects are organized in a tree like structure. In OSG this structure and node related information such as settings of the position of the objects, animations of objects, or definitions of logical relationships between objects are represented. This gives planners a clear understanding of the structure of the MS: the facility is the root, machines are usually nodes and the parts of the machines are leafs with additional information, such as dynamics and material characters.

In built scene graph several basic functions could be performed, such as view, navigation and manipulation of scene. Furthermore, by means of simulation, e.g. via the finite element (FEM) software DEFORM3D[3], analysis of machining processes in VFs becomes possible.

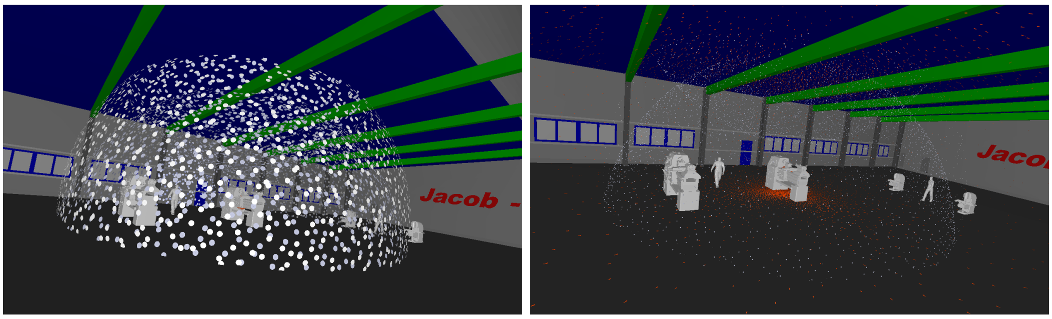
Based on our framework, SMEs will be able to build a software system to optimize facility layout and train their workers in a virtual and safe environment with low acquisition, administration and maintenance costs while reducing the time required for planning and training.

[1] OpenSceneGraph website: www.openscenegraph.org/projects/osg (2010)
[2] 3DS Max website: usa.autodesk.com (2010)
[3] DEFORM3D website: www.deform.com (2010)

4 Noise study example in a factory model

Noise from machining processes is one of the most frequent occupational hazards, it influences workers health and can even cause diseases. In Germany, about five millions employees are exposed to noise, which may cause hearing damage[4]. Therefore, it is important to analyze the noise in the VF. In this section we show an example implementation for sound analysis in a virtual model of a factory using our VF framework. A lot of research has been done in developing algorithms for indoor sound simulation. It is beyond the scope of this work to discuss these methods, the interested reader is referred to [8] for a detailed description of existing approaches.

For simulation of the sound in a VF based on given geometry, sound sources, and sound absorption at the surfaces, we integrated the phonon tracing algorithm described in [2] into our framework. In the "Data Acquisition Level" two passes are performed. In the first pass (phonon tracing), the method computes the energy or pressure decomposition for each sound particle (phonon) sent out from a sound source. In a second pass (phonon collection), the information is used to construct the impulse response (IR) for different listeners. IR is saved as ASCII file and imported to a scene graph. And from the IR, different metrics such as sound intensity (indicating the noise level) can be derived. Phonon tracing is coupled with an interactive visualization showing the sound propagation from a source, sound waves reflected from the scene, as well as received sound energy at a listener position. For more details about phonon tracing as well as sound visualization methods please refer to [2, 8].



(a) Sound particle propagation **(b)** Sound particle reflected from the floor

Figure 5 Sound visualization example

In the "Application Level", the sound simulation results is visualized in scene graph. Figure 5 depicts an example of sound visualization in a VF. The left figure shows sound particles building a wave front emitted from a machine, while the right figure shows particles reflected from the floor. The visualization of the sound propagation helps to identify the propagation of noise. The effect of different materials on the spectral energy/pressure distribution can be observed. The first few reflections already show whether certain frequency bands are rapidly absorbed and how much sound energy is reflected back into the scene causing a higher noise level. Scene materials of high reflectance can be identified and replaced in the virtual model to reduce the noise level in the VF.

[4] Federal Institute for Occupational Safety and Health (BAUA) website: www.baua.de (2010)

5 Conclusion and future work

In our paper we have discussed the human-centered VF concept and shown an example implementation to study the noise in a VF. Our scene-graph-based visualization framework is shown as a good choice for SMEs to implement various applications and fulfill their need of human factor study. The open structure of the visualization framework enables initiative applications to adapt enterprises depending questions in MSs. On the other hand, to perform such applications more available data sources and interfaces are needed. For example, to validate the sound simulation results, measurement data is requested. In the future work, these issues will be taken into account. Furthermore, more aspects of the human factor will be included into our VF model, and the use of VR systems for human-centered VF will be investigated.

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