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S. Metag / S. Husung / H. Krömker / C. Weber

User-centered Design of Virtual Models in Product Development

Introduction

Before a product is developed into a marketable commodity and can be produced many decisions have to be made. Typical questions are: What are the requirements of the market concerning the future product? How can these requirements be fulfilled by product functions? What characteristics of the product support production ability and competitive strength? To answer these questions it is important to get relevant information about the future product as early as possible. The information helps to surely evaluate the product. As an important tool for the evaluation of product features virtual reality (VR) established in product development for some time past. The representation of product data by means of virtual models is already used in early stages of development and extends to the production and commissioning of the product.

The demand for a more efficient product development process, for example simultaneous engineering or the transfer of processes and decisions in the early stages of development requires validation of the early results using digital, virtual models. But virtual reality should not be a media exclusively for experts, but all persons involved in product development. VR should provide a platform for evaluation, engineering and communication due to high versatility, flexibility, accuracy and a high degree of realism. Other important attributes excelling virtual reality are cost efficiency and an ecological management of resources.

Motivation

When designing and developing a product with the help of virtual reality, a virtual environment has to be created which complies with the requirements of product development. From a technological and technical point of view, virtual reality is already an established medium for displaying product data. Significant gaps, however, arise from the conception of an appropriate human-machine interface for virtual environments. Currently there are no guidelines or parameter for generating adequate, user-centered und task-oriented product representations with the help of virtual models. In addition, the characteristics of a product can only be assessed sufficiently precise and secure in virtual reality if human senses, especially the visual, audio and tactile perception, can be adequately stimulated.

Other demands arise from the product data management. It is the declared aim to generate a general, continuous data model of the future product and to integrate any relevant information and knowledge. The earlier information is available in the development process the more cost-efficiently and surely decisions can be made. In future the data model will include information beyond the pure geometry data. This will make it possible to develop virtual models, which also contain semantic information, such as material parameters, mechanisms of action, kinematic structure information or constraints - in addition to geometric (surface) data. Thus virtual models become quite interesting for a variety of tests and simulations.

The following questions result from the possibility of a wide range of use:

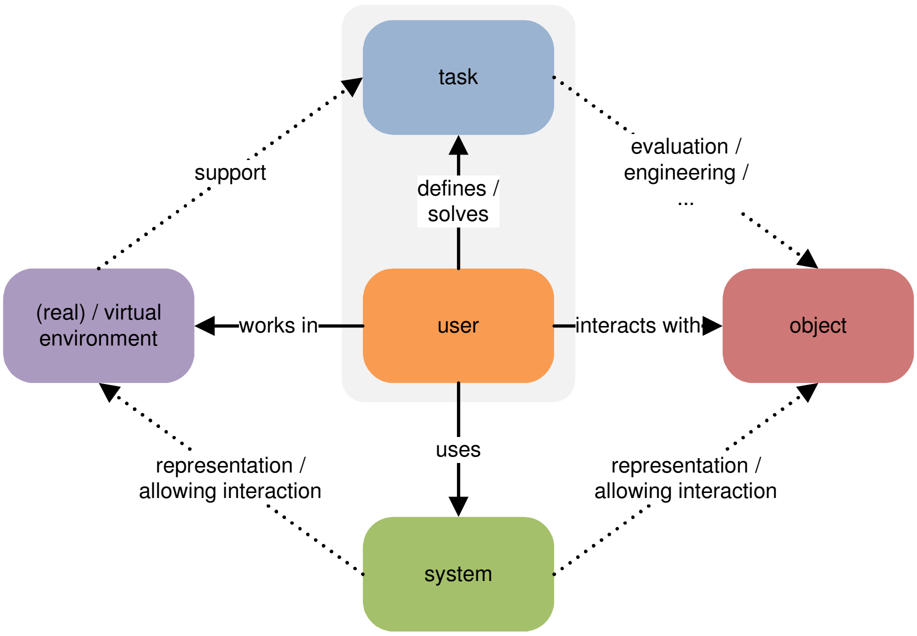
- What tasks can be usefully solved in virtual reality?
- What is the appropriate form of the virtual model for each user?
- What kind of data, information and knowledge is needed for the presentation in the framework of process and task?
- What level of abstraction and realism is useful and necessary for the virtual representation?

Summing up the central question can be posed:

What are the requirements of users concerning the virtual environment and the virtual model for an effective and efficient completion of tasks?

Systems Engineering

There is a reference system consisting of the components *user*, *task* and *system*. According to Bowman (2005) [1] the following factors are relevant: *task, users, virtual environment* and *technical system*. A similar classification can also be found at Witmer & Singer (1998) [2]. For optimum balance of these components the concept of the virtual environment must be done with consideration of ergonomic aspects. Figure 1 presents the relations of the individual factors, defined in this publication. Thereby the user plays a central role. According to its needs, its sensory and physiological parameters and its requirements the virtual environment has to be designed. Similar to the user the task is also a largely invariant measure[1], nearly a constant. Requirements arising from the nature of the task decisively influence the virtual environment. In addition to Bowman's classification the *object* - in this case the product to be developed – is presented as a single component in Figure 1. It contains data and information, depending on the task to be processed. The object's presentation and integration into the *virtual (working) environment* will be the subject of this work.



1: User-centered design of a virtual environment

While respecting the specificity of a virtual working environment, especially the aspect of realizing immersion of the user, the *natural environment* affects the ergonomic design in addition to the above factors. Its influence decreases with an increasing degree of

1

User can adopt to the virtual environment through learning processes, that means they are partially variable. Also the task can change due to the using of virtual reality.

immersion of the virtual environment. The real environment is therefore not separately listed in Figure 1, but assigned to the component *virtual environment*.

User Analysis

A detailed analysis helps to define the specific requirements of users according to the virtual environment and the virtual model. Relevant characteristics were defined by Redish & Wixon (2002) [3], Shneiderman (1997) [4] and Bowman (2005) [1]. The most important characteristics are:

- Age, sex
- Specifics of sensory perception and cognitive information processing
- Physiology
- Media competence, knowledge of VR technology, expectations
- Expertise in relation to the task, motivation

Based on these specifications the human-machine interface can be designed.

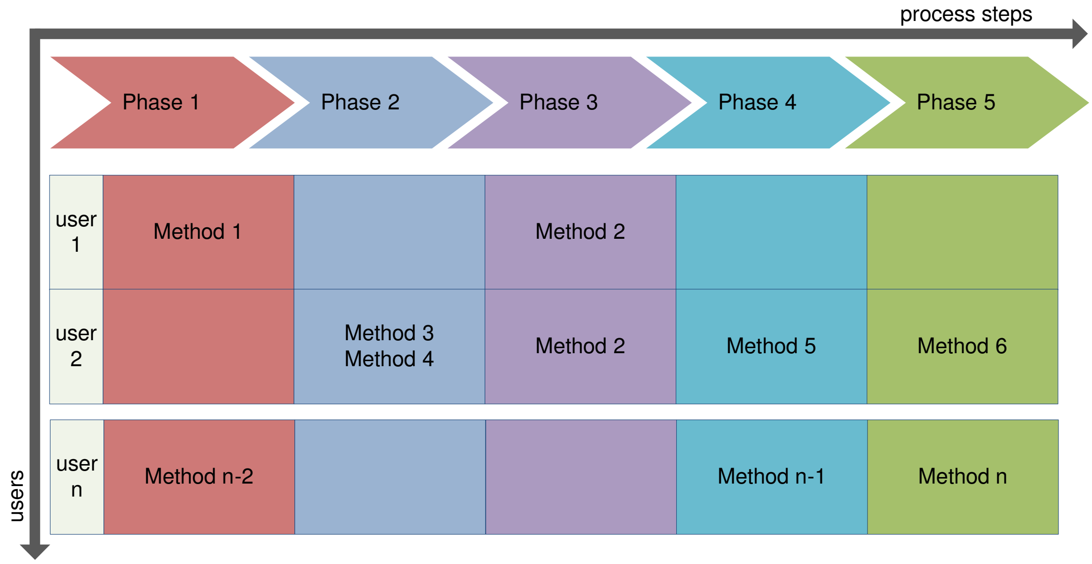
During development a product or rather a technical system passes numerous phases and process steps. Different users with different relationships to the product or the product development process are involved. The investigation of typical product development cycles can determine the target group. Empirical studies using methods of usability engineering with the identified target groups will allow a detailed description of the user specifics afterwards.

Task Analysis

The analysis of tasks and working environment is also one of the basic analysis measures of the usability engineering. The parameters of a task decisively influence the requirements for the work equipment - in this case the work equipment is virtual reality.

In the field of real, natural working environments, scientific institutes for ergonomics defined numerous directives and laws. For 2D user interfaces for computers a lot of guidelines (heuristics, style guides) have been developed by software ergonomics. But if it is for three-dimensional, virtual work spaces, there is a lack of appropriate descriptions.

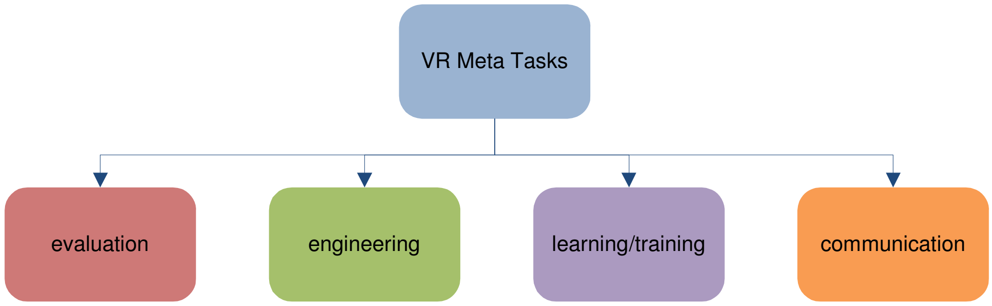
A first step towards the design of VR work environments can be done through analysis of the product development process, because task and process are in direct relationship and mutually interdependent. General product development processes can be found at Ulrich & Eppinger (1995) [5], Pahl / Beitz (1995) [6] or in the VDI Guidelines 2221-2223 [7]. With the help of these production systems complex and simple tasks can be identified. Afterwards people and necessary task-solving methods are assigned. The resulting matrix is outlined in Figure 2.



2: Process-Task-User-Matrix

From this approach, however, the following problems result. The relevance and the actual use of such systems in companies are not ensured by recent studies. There are potentially industry-specific and product-specific differences.

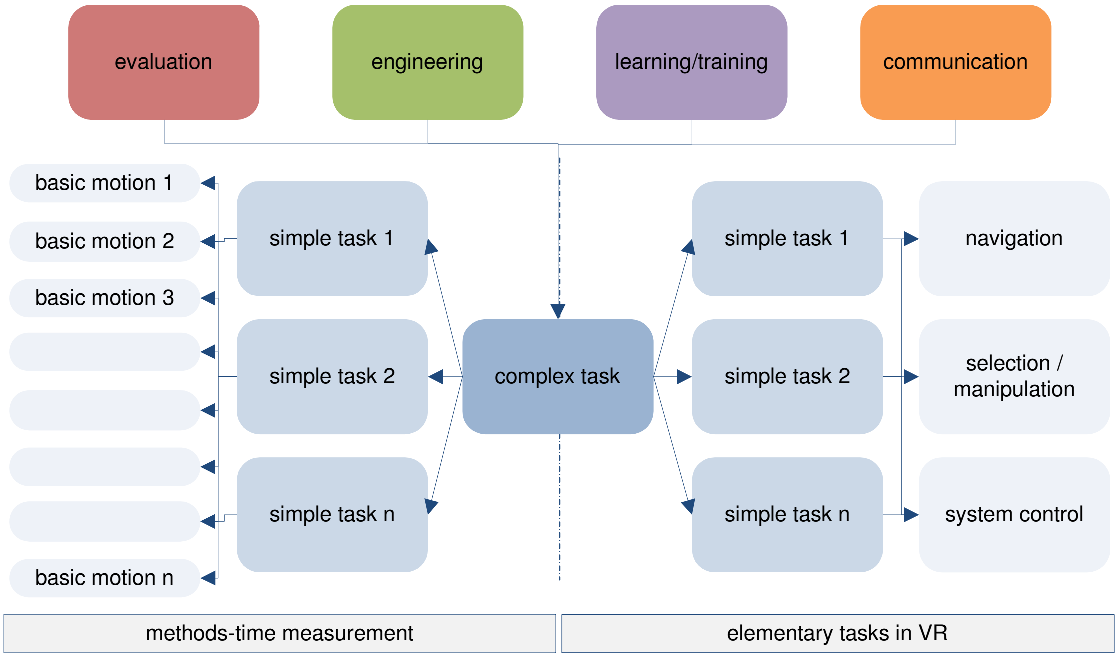
The existing classification systems do not allow a conclusion pertaining to the use of virtual reality for the task. Under certain circumstances not all tasks can be implemented in VR meaningful and effective. Stanney et al. (1998) [8] declared visualisation, simulation and training the central tasks. With increasing technical capabilities and a higher degree of interactivity and "intelligence" of VR models the range of tasks can be expanded. Within the analyses it is useful to define a level of meta-tasks. These meta-tasks help to describe the task characteristics, but they are not practical for the generation of specific requirements for VR. An overview is shown in Figure 3. More specific product development tasks can be assigned to the meta tasks.



3: meta tasks in virtual product development environments

A derivation of requirements from the systematized tasks of the product development process is usually not easy to do due to the complexity of the task and its dependence on environment parameters. A division of the basic tasks in nuclear activities could be a solution of the problem. Thereby any complex task could be synthesized by a limited number of basic activities. The basic activities may be described very well and have to empirically investigated. Both ergonomic sciences as well as the usability engineering for virtual reality are proposing models. Thus, the possibility of measurement and optimization of (manual) activities is provided by the MTM[2] process (Hettinger & Wobbe, 1992 [9]). Eight basic movements for the hands and arms, view functions and movements of the legs and body are defined. Another similar approach for the optimization of three-dimensional graphical user interface (GUI) was developed by software ergonomics. This approach distinguishes between the basic activities of navigation, selection / manipulation and system control. A nomenclature for the division of complex tasks in elementary basic activities is shown in Figure 4.

[2] MTM: methods-time measurement, system to analyze industrial work, created by Frank Bunker Gilbreth



4: Two Systems for creating Elementary Tasks

On the basis of the extracted basic activities empirical studies can be developed. According to Bowman (1999) [10] and Poupyrev et al. (1997) [11] the following criteria have to be determined in these studies:

- User
- Task context
- Application
- Interaction metaphors
- Input / output devices

Methodical basics for an empirical investigation have been created inter alia by Bowman (1999) [10], Bowman et al. (2002) [12], Sutcliffe & Gault (2004) [13], & Sutcliffe Kaur (2000) [14], Kalawsky (1999) [15] and Stanney et al. (2003) [16].

It is, however, to prove to which extent the decomposition into basic activities is useful for the derivation of requirements and which of the proposed models is suitable. In addition the consequences of the increasing use of virtual reality on the product development process in general and on the design of tasks in particular are still not clear. These retroactive effects are not taken into account in the few years old models for product development process.

Object / Product Analysis

As part of the product definition, requirements for the product are formulated. These mainly come from the customer, but also from the company's ideas on market development and the company's philosophy. Properties of the future product have been derived from the defined requirements. During product development the required properties have to be realized in the various phases and the compliance has to be ensured. Therefore numerous methods and processes, such as simulation / animation, prototypes or mock-ups are available. Virtual Reality can decisively support these processes. A virtual model aiming at a specific task and a specific user group has to be generated out of the development data of the product.

The virtual model (the *object*) accordingly plays a central role. With the help of the virtual model it must be possible to make decisions, to plan the development, to do optimization or corrective actions and much more. The way of the object representation, the integration into the virtual environment and the use of different sensory channels of the people as well as the interaction with the object have to support the representation of the properties of the future product.

Each product development stage aims at the reduction of the difference between the nominal properties (out of the requirements) and the actual properties (from the current state of development of the product). The properties, however, cannot directly be manipulated because they sometimes have an abstract or subjective nature[3]. Their characteristic also depends on a variety of components of the product. The properties are interdependently associated, so that changing a property *A* can also change a property *B*. According to the VDI guideline 2209 (2006) [17], the properties of a product can be influenced by its characteristics. These characteristics of the product must therefore be displayed by the virtual object to evaluate the development status of properties. That is to decide what data and information is to integrate in the virtual model. Furthermore demands of designing the representation of the model in the virtual working environment result from the property to be evaluated.

3 They can only be clearly defined by numbers, formulas or text. Some properties are only describable as abstract criteria.

Initial studies have shown that the product characteristics can be mapped onto each product type, but the meaning and expression of the characteristics between different types of products may vary significantly. It can be concluded that an analysis of object representation according to the representation of properties in virtual reality is meaningful and purposeful.

Summary & Outlook

In this publication an approach for a user- and task-centered design of virtual reality for product development has been presented. Therefore relevant parameters for user-friendliness or rather usability were identified and their relationships to each other were systematized. In addition, first analytical approaches for analyzing these parameters were identified.

In future empirical studies should be developed and implemented, which focus on the description of the above parameters. This requires appropriate, measurable criteria. Some could already been presented in this publication. For the methodical investigation, there are currently only a few approaches. It must therefore be proven which methods of usability engineering and other disciplines are suitable and appropriate and which adjustments should be done due to the specialities of virtual reality. To generate representative and valid results the case studies should be performed with the help of industrial products. These products will have significantly different weighting of product characteristics.

The central results of the investigations are design guidelines for virtual work environments. Using these guidelines will make it possible to develop and to manufacture products efficiently, effectively, competitively and not least from an ecological point of view with the help of virtual reality.

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