Design and evaluation of a VR-user-interface based on a common tablet-PC

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Virtual Reality systems are an essential element of the product development process, but common VR-user-interfaces still need intensive practice to be effectively used to solve tasks within Virtual Environments. This keeps especially non-expert-users from using the full potential of VR for evaluating virtual models during the product development process. In this article, we present a concept for an intuitive to use VR-user-interface based on a common tablet-PC. A rudimentary evaluation performed as a preliminary study showed an initial tendency for the usability of the implemented prototype.

Virtual Reality, Virtual Environment, Tablet-PC, VR-user-interface, Usability

1. INTRODUCTION

Virtual Reality (VR) is an important tool to support the rapid development of new products (Straub & Riedel 2006). Especially where huge and complex products are created – for example in aviation and automotive industry – VR is used since several years (Ottosson 2002).

Driven by the idea to replace physical mock-ups – which are expensive and take a long time to create – by virtual ones within the not so distant future, especially people from the aviation and automotive industry are investing many efforts in developing VR to make the technology more suitable for the product development process.

Through the fast IT-hardware and software development over the past years it is now possible to create, display and interact with almost entirely realistic virtual mock-ups and environments. This helps to visualise new products at a very early stage of the development process and evaluate the product for example in matters of producibility or aesthetics.

Although the highly developed technology provides lots of possibilities, VR is mainly used for basic evaluation during the early working process, but not for the last evaluation of the future product. For this purpose usually physical mock-ups are used, which leads to the assumption that virtual mock-ups don't receive a full acceptance during the product development process. Considering the literature, one can find a correlation between interaction and technology acceptance:

Davis (1989) identified the **perceived ease of use** of a technology as one of two main attributes that influence the acceptance of information technology.

Semi-immersive VR-systems are commonly used by expert-users who are creating the Virtual Environment (VE) and non-expert-users who are evaluating the VE under certain aspects. The interaction with the VE is mainly done via special VR-interfaces which are complex to use and need a long time for acquisition. Intuitive and easy to use interaction devices for non-expert-users do hardly exist. A common solution to offer interactivity within the VE for example for evaluation purposes for non-expert-users is to use an operator who navigates within the virtual world based on commands from the non-expert-user.

This form of interaction often leads to misunderstandings and frustration during the evaluation process, which may reduce the acceptance of VR for the development process.

A basis for increasing the acceptance of VR for evaluation purposes within the product development process is the possibility of an individual interaction within VEs for non-expert-users.

2. INTERACTION IN VIRTUAL ENVIRONMENTS

Virtual Environments differ from common "desktop-computing" environments. Thus researched and proven guidelines and heuristics for user-computer-interaction can't easily be adopted for interacting in VEs. Bowman et. al (2001) state that there is a sample of universal interaction tasks in VE:

- Navigation
- Object Selection
- Object manipulation
- System control

To offer those interaction tasks and fulfil user's needs, a huge amount of VE input devices were developed and implemented for various VR-Systems. Those are for example spacemouse or ordinary keyboard and mouse devices which are commonly used for the interaction within semi-immersive VR-systems or Flysticks or Cybergloves for the interaction with highly-immersive VR-systems.

Gabbard (1997) as well as Poupyrev and Kruiff (1999) give a detailed overview of different input devices.

3. DESIGN AND IMPLEMENTATION

For the conceptual design and the implementation of the prototype the concept of Object Engineering (see fig. 1) by Rupp (2002) was used as a methodical process. The development process was divided into five different stages, beginning with the definition of specific goals and the identification of possible users. This step was followed by the definition of necessary requirements and possible use-cases. Afterwards the different software classes and state diagrams were created followed by the main implementation of the prototype. In the end the prototype was tested under the perspective of usability. Therefore, evaluation criteria were defined.

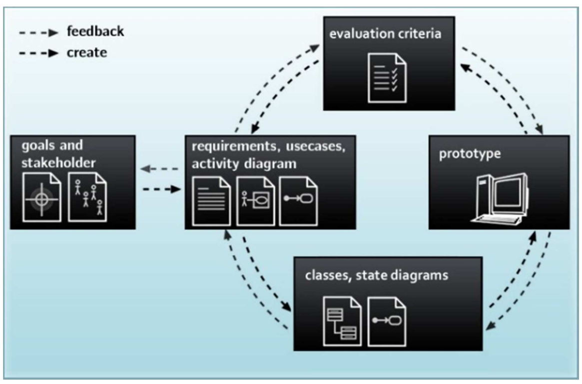

Figure 1: *Process model Object Engineering from Rupp (2002)*

3.1 Goals and Stakeholders

The goal of the project was to create the possibility for non-expert-users to interact individually with a semi-immersive VR-system. The investigated system is used in the automotive industry to evaluate the look-and-feel and the quality of a future car in a late state of the product development process.

The main focus was set on the appropriate gathering of requirements for the user-interface from the different non-experts using the VR-system for the above mentioned evaluation purpose.

In addition a tendency of the usability of the designed user-interface had to be measured. Hence the usability characteristics **effectiveness** and **user-satisfaction** as well as a fundamental measurement of the **efficiency** were evaluated during a preliminary study.

The investigated semi-immersive VR-system is used by different roles. These roles contain VR-operators as expert-users and members from the production planning, development, design, quality assurance and top-management as non-expert-users.

While the tasks of the expert-users contain building and updating the virtual model, the non-expert-users exclusively evaluate the virtual model under certain role-specific aspects. These aspects are all considering the future product concerning its look-and-feel and its quality. In this context mainly the evaluation of the size and visual parallelism of gaps as well as the visual homogeneity of surfaces – for example regarding possible inaccuracies during the development as well as future production processes – is done. These evaluations are mainly undertaken with respect to certain viewing-perspectives which are custom-relevant perspectives.

The target group for the planned user-interface are the mentioned non-expert-users of the investigated VR-system, as we believe that the direct interaction of the evaluators will raise the acceptance of the investigated virtual model for evaluation purposes.

3.2 Requirements

To gather necessary requirements for the design of the user-interface, two different methods were used. On the one hand field studies were done to get an overview over specific functions which were used within the VR-system to solve the current evaluation tasks. On the other hand interviews with 16 participants from the different involved roles (6 participants from production planning, 4 from development, 2 from quality assurance, 3 from design and 1 from top-management) who are using the VR-system for evaluation tasks, were performed to

(i) gather information about non-functional requirements considering the design of the user-interface
(ii) identify functional requirements the user-interface has to offer to effectively and individually perform future evaluation tasks

The collected information has been interpreted with respect to functional and non-functional requirements which are relevant for the user-interface. The following non-functional requirements have been subsumed:

- The elements of the user-interface have to be self-explanatory at first sight and intuitive to access
- The user must not have to acquire special actions for interacting with the virtual model (e.g. gestures, use of special devices, etc.)
- The user must always have the impression of having full control over the VE (e.g. not be able to make mistakes and therefore make a fool of himself)

The functional requirements have to make the actual evaluation possible for non-expert-users. Since the non-expert-users just evaluate the model and do not create them, the set of universal tasks by Bowman et. al (2001) can be reduced to **navigation** and **system control**. The following functional requirements for navigation-tasks have been identified during the performed interviews:

- unrestricted navigation within the VE
- restricted navigation (Fly to a predefined Point Of Interest (POI))
- Reset to predefined position

In addition the following functional-requirements for system-control-tasks have been identified during the interviews as essential ones for the evaluation of the look-and-feel and the quality of the future product:

- Define different viewing heights (customer-relevant perspectives)
- Change to colour of the virtual model (gap evaluation)
- Switch to analytical representation of the virtual model (surface evaluation)
- Rotate the virtual model (general impression of the virtual model)

3.3 The prototype

A main demand for the prototype was an intuitive-to-use and fast-to-adopt user-interface. Since common consumer tablet-PCs are widespread, it is assumed that potential users are likely versed in interacting with those devices. In addition the functionality with respect to the technical potential (e.g. latency) as well as the variability in terms of realising interactive user-interfaces on one device is an advantage characteristic.

Figure 2: *The final prototype*

Therefore a tablet-PC using the android operating system was used as the physical interaction device. On this device a graphical-user-interface (GUI) with the demanded functionality with respect to the non-functional requirements has been implemented as the actual prototype. Figure 2 shows the final prototype as it was implemented on a standard consumer tablet-PC.

The user-interface acts as a remote control for the investigated VR-system. By performing an action with the user-interface, the certain function within the VR-system is triggered and executed.

To access the different functions, the GUI was designed with two different tabs which contain the elements for navigation and for system control.

Since the navigation within the VE is the main requirement, the first tab contains the functions for navigation. These are the restricted as well as the unrestricted navigation. The restricted navigation is triggered via different buttons that show the certain POI. These buttons can also be used as a reset function in case the user gets lost in the VE while interacting with it. To reduce the complexity of the unrestricted navigation, an image of the actual virtual model is displayed. Via direct manipulation of this image, the navigation within the VE is performed. This reduction of complexity avoids the acquisition of special actions (e.g. gestures) to interact with the virtual model. In addition to that, the pinch-to-zoom gesture is used to zoom into or out of the scene.

Within the second tab the additionally requested four different system control functions are accessible. These functions were requested to be able to not only inspect but also evaluate the virtual model with respect to its look-and-feel and its quality.

3.4 Evaluation criteria

A rudimentary evaluation of the effectiveness of the prototype as a preliminary study was the main evaluation criteria for the designed VR-user-interface. Since the non-expert-user weren't able to interact individually with the VE before, the concept for the prototype would be rudimentary positively evaluated if the subjects were able to perform basic navigation tasks, using the implemented functions for system control and being satisfied using the user-interface while performing the defined tasks.

4. USABILITY EVALUATION

To gain information about the prototype a rudimentary usability evaluation as a preliminary study with respect to effectiveness, efficiency and user-satisfaction was performed. Therefore 27 subjects (2 female, 25 male, average age of 39 years) belonging to five different roles (15 subjects belonging to production planning, 3 to design, 4 to development, 2 to quality assurance, 3 to top-management) were asked to evaluate the designed VR-user-interface.

To get information about the effectiveness the subjects were asked to solve a set of basic tasks with the use of the different implemented functions. To get information about the efficiency the time for completing these tasks was measured.

Finally the subjects were asked about their former experience with tablet-PCs. To measure the experience, the subjects were asked to rate their usage of the different systems on a five-item Likert-scale from 1 – never, 2 – rarely (less than monthly), 3 – occasionally (monthly), 4 – regularly (weekly) to 5 – frequently (daily).

In addition to that, the subjects were asked whether they experienced joy-of-use (possible answers: yes/ no) while using the user-interface as well as if they perceive an increase of the evaluability of the virtual model (possible answers: yes/ no). In the end the subjects had the possibility to recommend necessary improvements of the prototype to make it more usable for the evaluation of the virtual model.

4.1 Usability tasks

To get information about the usability of the VR-user-interface and a possible usage within the specified context, tasks which meet the actual performed tasks for the stated evaluation purposes had to be designed. Therefore, two different subsets of basic tasks have been generated.

The first subset of tasks was given to get the subjects used to the user-interface and to gather information about the usability of the restricted navigation as well as the system control functions. Therefore the subjects had to

(i) Navigate to three different POIs
(ii) Use three different system control functions (Change colour, Define viewing height and switch to analytical representation)

The second subset of tasks was given to gather information about the usability of the unrestricted navigation within the VE. Therefore the subjects were asked to navigate to four different POIs and search for different geometric primitives. These primitives were hidden under different parts of the car as illustrated in figure 3.

The first task was used to get the subject known to the unrestricted navigation. The time from the start of the searching until the subject found the

Figure 3: *Different tasks for unrestricted navigation and searching within the VE – white circles weren't visible during the test*

geometric primitive has been measured to gather additional information about the efficiency of the user-interface.

4.2 Results

Analysing the subjects experience with the tablet-PCs, 27% stated they had never used a tablet-PC before. 15% stated they had rarely used, 15% occasionally used, 12% regularly and 31% frequently used tablet-PCs. Figure 4 shows the stated experience of the subjects with the different systems in an overview. Getting a conclusion concerning the effectiveness and a possible usage of the user-interface, the different mentioned tasks had to be accomplished successfully. The result of both subsets of tasks was throughout positive. 100% of the 27 tested subjects were able to solve the first subset of tasks for restricted navigation as well as the use of the system control functions.

The second subset of tasks for unrestricted navigation as well as searching for geometric primitives by inspecting the virtual model individually was accomplished by 100% of the 27 subjects – all of the subjects were able to individually navigate unrestricted within the VE and were able to find the hidden geometric primitives.

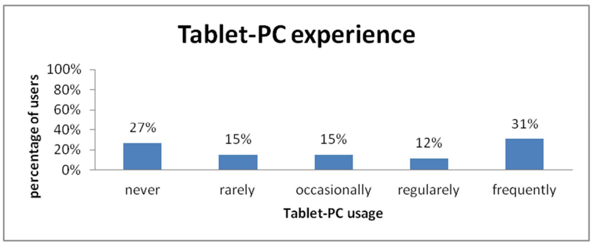

Figure 4: *Distribution of the subjects stated experience with tablet-PCs, VR-systems and CAD-systems*

Considering the efficiency of the user-interface, the time from the beginning until the subject found the geometric primitive was measured. The subjects who stated they never used tablet-PCs needed an average time of 45.9s (*SD*=33.2) to complete task A. To complete task B they needed an average time of 19s (*SD*=15.2) and to complete task C an average time of 15.9s (*SD*=9) was needed. The time consumption for subjects who stated they rarely use tablet-PCs, the completion of task A took in average 37s (*SD*=22.4), task B in average 25.5s (*SD*=9.8) and task C in average 20.3s (*SD*=4.2). Subjects who stated they occasionally use tablet-PCs needed an average time of 17.3s (*SD*=9.3) for task A, 13.5s (*SD*=3.9) for task B and 15s (*SD*=13.4) for task C. Subjects who stated they regularly use tablet-PCs needed an average time of 15s (*SD*=2.6) for task A, 19.7s (*SD*=13.4) for task B and 14s (*SD*=8.7) for task C. Subjects who stated they frequently use tablet-PCs needed an average time of 17.3s (*SD*=6.6) for the completion of task A, 14.3s (*SD*=5.7) for task B and 17.5s (*SD*=11) for task C. Figure 5 shows the time consumption for finding the object for the three different tasks with respect to the stated tablet-PC experience of the subjects.

Considering the user-satisfaction, the subjects were asked whether they experienced joy-of-use while using the user-interface for performing the tasks. 100% of the 27 subjects stated they experienced joy-of-use while performing the tasks.

In addition the subjects were asked if they believe that the perceived evaluability of the virtual model was increased by the user-interface and the given opportunity if the individual interaction. 81% of the subjects stated they believe that the perceived evaluability of the virtual model has been increased by the possibility of the individual interaction.

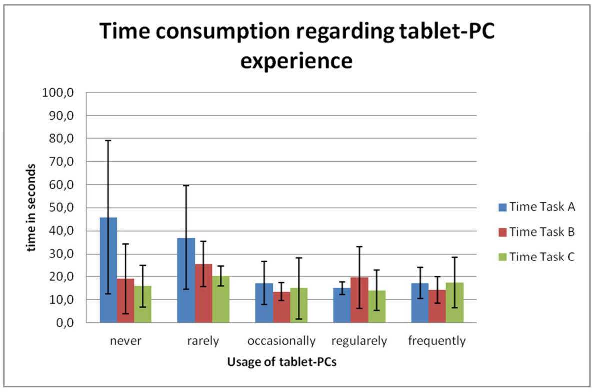

Figure 5: *Time consumption for finding the hidden geometric primitives with respect to the subject stated tablet-PC experience*

5. DISCUSSION

The goal of this work was to design, implement and evaluate a prototype of an intuitive user-interface for non-expert-users of a semi-immersive VR-system. The concept was evaluated with a rudimentary usability evaluation as a preliminary study.

To define the prototype, a subset of functional and non-functional requirements for the user-interface in the context of the evaluation of the look-and-feel and the quality of a future product were identified.

A common tablet-PC was used as the interaction-device, since it was assumed that the experience of such devices by potential users is quite high. This assumption applied since over 50% of the subjects stated that they at least occasionally (monthly) use tablet-PCs.

The identified functional requirements with respect to the non-functional requirements have been implemented on the user-interface and finally evaluated in a preliminary study.

As stated earlier the sample of universal interaction tasks mentioned by Bowman et al (2001) was reduced to navigation and system control for the specified task evaluation of the look-and-feel and the quality of a future product by non-expert-users within the investigated VR-system. In further studies it should be investigated whether the sample of universal interaction tasks still contains **object selection** and **object manipulation** for different tasks.

Referring to the rudimentary usability evaluation, since 100% of the subjects were able to solve the given tasks on the one hand there is a possibility that the task for evaluating the user-interface was too easy. On the other hand it may be possible that non-expert-users are able to solve real evaluation tasks within a VE individually with an appropriate user-interface.

Considering the results of the time measurements for the task completion, subjects who stated to have never or rarely used tablet-PCs show a drop in the time needed to solve tasks A to C. However, the standard deviation was enormous during the performed tasks. These results as well as the efficiency measurements of the subjects with more experience can just be taken as a tendency for a fast acquisition and intuitive-to-use user-interface. This tendency has to be evaluated during further usability tests.

Since the design of the user-interface is **work in progress**, the designed user-interface will be extended by a few improvements – for example the translation of the focus point – as recommended by the subjects after the usability evaluation.

After these improvements, a broad usability study of the final user-interface with more representative tasks as well as an evaluation under real working conditions have to be undertaken to investigate the actual usability of the designed user-interface.

Nevertheless, this study shows a systematic approach to design an intuitive VR-user-interface for non-expert-users using a standard “Commercial off the shelf” device contrary to the common development of user-interfaces for VR-systems where new devices are created instead of using common existing devices. This approach shows that there is a possibility for developing intuitive user-interfaces for non-expert-users of VR-systems which could raise the acceptance for the use of Virtual Reality during the product development process.

6. REFERENCES

Bowman, D., Krujiff, E., LaViola, J., Poupyrev, I. (2001) An Introduction to 3-D User Interface Design. *Presence*, 10 1, 96 – 108.

Davis, F. (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13 3, 319 – 339.

DIN EN ISO 9241-11 (1999) *Ergonomic requirements for office work with visual display terminals*. Beuth, Berlin.

Gabbard, J. (1997) A Taxonomy of Usability Characteristics in Virtual Environments. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.99.6728 (June, 07th 2012).

Ottosson, S. (2002) Virtual Reality in the product development process. *Journal of Engineering Design*, 13 2, 159 – 172.

Poupyrev, I., Kruiff, E. (1999) 20th Century 3DUI Bib: Annotated Bibliography of 3D User Interfaces of the 20th Century. http://people.cs.vt.edu/~bowman/3dui.org/bibs/3duibib.pdf (June, 07th 2012).

Rupp, C. (2001) *Requirements Engineering und – Management*. Hanser, München.

Straub, K., Riedel, O. (2006) Virtuelle Absicherung im Produktprozess eines Premium-Automobilherstellers. In Dietrich L., Schirra, W. (eds), *Innova-tionen durch IT*. Springer, Berlin