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Methodology for Immersive Emotional Assessment of Virtual Product Design by Customers

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Abstract

This paper presents a novel, integrated methodology for customer-centered emotional assessment of future products during the early conceptual design stages. This methodology integrates the technologies of Virtual Reality and emotion recognition in the simultaneous, interconnected processes of product development and market research. Its goal is to provide relevant emotional customer feedback during the interactive experience of only virtually existing conceptual product designs at early development stages. In this way, the company can identify which product designs would be suitable for future products. The novelty aspect of the methodology lies in the structured integration of experts from various disciplines with specific roles. It enables the often neglected holistic approach to the task. Each participant can identify best solutions to problems from their area of expertise and contribute to solving interface problems in a synergetic manner. The presented validation study proved the coherence of the methodology and showed clear preferences for concrete technological solutions regarding the state of the art and the future potentials.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual reality—Applications

1. Introduction

The market success of a modern company significantly depends on customer satisfaction. For this reason it is important to involve customers continuously in the creation of product value, including the early conceptual stages of virtual product design. It is crucial to capture their emotional feedback on the virtual products, because consumers tend to make buying decisions increasingly emotionally, avoiding the rational processing of large quantities of information. This is why appealing to emotion was identified as one of the three success parameters of modern marketing [KM08]. Currently, customers are usually not involved in the "create" and "select" stages. This leads to numerous customer-oriented product ideas being dismissed without ever hearing their feedback. Less than 10% of the created solutions are pursued within projects, with less than 5% eventually turning into products [Sen09]. On the other hand, many product variants, which originate without the wish of the customer and are not perceived as appropriate solutions, are offered for sale. According to a study by the initiative "Network of Automotive Excellence" this is true for 30% of car variants [Sto04]. Hence, reliably capturing emotional customer feedback to future products, during the concept stages of their development, offers enormous potential for early identification of successful customer-oriented products. This task requires a combination of two types of technologies – those for experiencing and interacting with virtual products (eg. virtual reality) and those for performing emotion recognition (eg. physiological measurement). This paper presents an integrated methodology that makes use of these two technologies and proposes a novel, interdisciplinary approach for creating customer-centered products.

2. Virtual Reality and its Application in Product Development

Virtual Reality (VR) can be defined as "a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation" [SC03]. It is technologically realized through various output and input devices. The output devices conduct information to corresponding human senses, primarily the visual, acoustic and haptic ones. Input devices enable the user to navigate and

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manipulate the virtual world and thus becoming an active agent. The three basic properties of VR are [BC03]

- Immersion (integration of the user into the virtual scene)
- Interaction (bi-directional information flow between the user and the virtual scene)
- Imagination (the cognitive perception of the user stimulated by the representation)

Virtual Reality was identified as suitable technology for supporting product development processes. However, it has never reached the point of mass adoption. A major reason for this is the lack of a profound methodical approach, which integrates this technology properly in the bundle of simultaneous, heterogeneous activities during product development. Isolated examples illustrate the VR application for assembly [PWLY10] and design [BLRC03] purposes. Customers have already used VR for selection of individual configurable products, for example in the furniture industry [OyYH04]. However, no systematic capturing and evaluation of customer emotional feedback was performed, with their involvement occurring not in the concept phase, but later in the product development.

3. Assessment of Emotions for Products

Emotions can be defined as actual, object-related psychic states of humans, which are at the same time temporal, unrepeatable events with certain quality, intensity and length (seconds to minutes) [MRS01]. They can be described through discrete categories, which assign names to various emotional states, based on certain classification principles and behavior expressions. Their disadvantage is the ambiguous nature and large variety of possible classifications. Dimensional models on the other hand describe emotions as combinations of a number of orthogonal, quantifiable emotional dimensions. For example, the PAD model establishes the following three emotional dimensions: pleasure/valence (P), arousal (A) and dominance over the situation (D). The following are the three main method groups for capturing emotional feedback:

- Questioning methods
- Physiological measurements
- Observing methods

The questioning methods aim to capture the customers' written or oral emotional feedback in form of answers to questions asked. Closed questions allow only for a limited number of answers, mostly between five and seven, placed on an increasing or decreasing Likert scale. This scale is usually postulated as equidistant, thus allowing a statistical analysis of answers. Closed questions are restricting and require intensive conscious cognitive processing of affective reactions. Open questions allow free, creative answers. The description of the individual emotional effect to the experienced product through the use of adjectives is the basis for the Kansei Engineering approach [Yan11]. Physiological measurements are based on the quasi-continuous gathering of central (electroencephalography) or peripheral physiological signals (electromyography, blood volume pulse, electrodermal activity, etc.) of individuals. These signals feature strong correlations to dimensions of the PAD emotional model, for example the heart rate variability with the arousal dimension [KO09]. Observing methods rely on objective or subjective insights, gained from the careful observation of the individuals experiencing the product. These methods are based on ethnological approaches and are very time and resource intensive.

4. Novel Integrated Methodology EMO VR

This paper proposes a novel integrated methodology for reliable capturing of emotional customer feedback on conceptual product designs in Virtual Reality. It consists of six steps, which are summarized and illustrated on Figure 1. Iterations between these steps are reasonable and favored. Throughout all steps, intensive interdisciplinary communication between different stakeholders (engineers, designers, psychologists, marketing and VR experts) is necessary, in order to guarantee the generation of customer value. The following are brief descriptions of each step.

Step 1: Definition of the Variant Space for Developing Products

In this methodology it is assumed that the company has a general product focus, has experience with forerunner products and knows the general requirements of its customers with regard to future products. Based on these requirements, a variety of product ideas and concepts can be generated by engineers and designers. All of these concepts are modeled and implemented within a product configuration tool in VR, without pre-selection. In order to aid the customer's imagination, the context of product usage also has to be modeled realistically.

Step 2: Selection of the Lead User Group

The representative character of the study can be guaranteed only if the size of the lead user group allows statistically founded argumentation and its composition regarding key parameters corresponds to the composition of the targeted customer population. These key parameters have to be pre-identified through market studies. If only few parameters with only few value categories are identified, 20 to 40 participants are enough to guarantee the representative character [Bon05]. All customers have to take part in the study deliberately.

Step 3: Design of the Immersive Emotional Assessment Environment

The environment design has to be performed individually for every project, taking into account the current technolog-

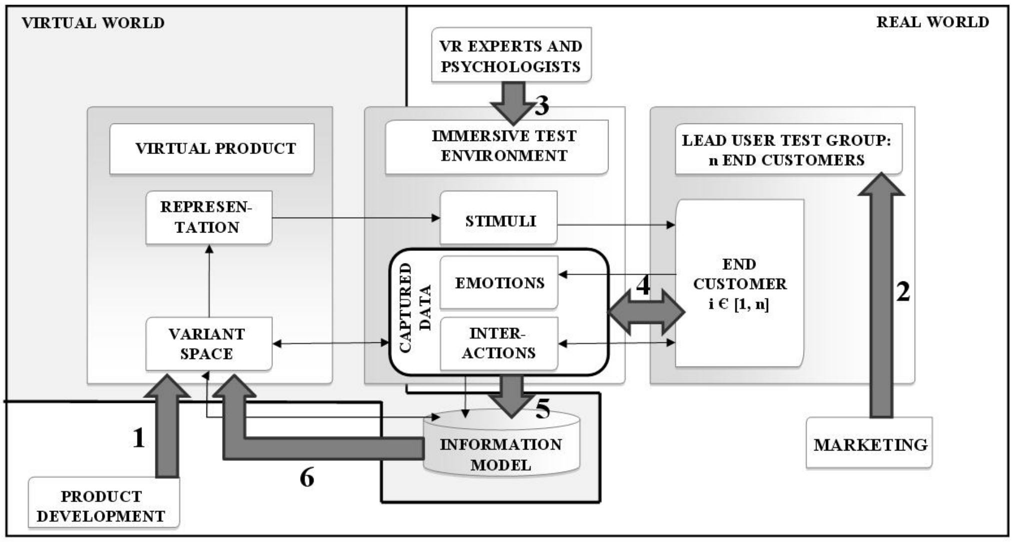

Figure 1: *The EMO VR Methodology*

ical and financial possibilities of the company. In a previous study with 102 participants, we could show that full-sized stereoscopic visualizations within CAVEs (Cave Automatic Virtual Environments), product design and functionality context-faithful and multimodal representations significantly improve the imagination of the customers in comparison to other VR technological solutions [OK11]. The applied techniques for interaction with the virtual world have to be easily learnable and routinely applicable, allowing the customer to cognitively and emotionally focus on the product and not on the interaction [OK11]. Electroencephalography (EEG) measurements need a fairly long preparation time of about 30 minutes and are, in our opinion, ethically disputable. On the contrary peripheral physiological measurements do not collect cognitive data and can be prepared in only 5 minutes. It has to be checked whether there is any interference between the planned Virtual Reality and emotion recognition technologies (for example, mimics recognition and 3D glasses, which disguise a great part of the face). Measurements can be combined with questioning techniques.

Step 4: Experiment

The comparability and reproducibility of customer feedback requires standardized experimental procedures. Prior to the core experiment of experiencing the product, sessions for emotional calibration and for familiarization with the interaction have to be planned. This paper proposes emotional calibration through randomized picture series from the International Affective Pictures System (IAPS), which induce certain emotional patterns describable with the PAD model [LBC08]. In order to avoid data corruption, the supervisors have to use standardized, emotionally neutral verbal expressions. The capture of interaction steps and physiological data must be synchronized, in order to allow the detection of causal relationships.

Step 5: Analysis of the Experimental Results

First of all, individual analysis of the results is performed. The comparison of physiological measurement data with the interaction steps reveals which products are the respective emotional activators for the corresponding feedback intervals. Certain values of the valence and arousal dimension in the PAD model can be assigned to the physiological data. Answers of open questions, usually Kansei adjectives describing the emotional effect of products, can be categorized into classes with certain emotional nature. Closed questions can be assessed directly. After the individual analysis is completed, statistical analysis for the entire test group and for defined relevant segments are performed. Location, dispersion and correlation parameters can be calculated for the answers of closed questions and the results of physiological measurements. Open questions have qualitative nature and thus only the number of mentions for each category can be calculated. It describes the predominant image of different product variants.

Step 6: Return of Results in the Product Model

The statistical analysis of the emotional feedback provide information on which product variants are particularly appealing to which customer groups. All other variants can be dismissed, so that the variant space is reduces in a customer-centered way. The gathered feedback is saved in the product

Key parameter	Composition
Sex	Male: 11 Female: 10
Age	21 to 30 years: 8 31 to 40 years: 6 Above 40 years: 7

Table 1: *Composition of the Test Group*

Figure 2: *The immersive emotion assessment environment with the use case of car configuration system*

database, where it can be eventually represented in various forms, which are suitable for different stakeholders.

5. Validation Study

To validate the presented methodology, a study with 21 participants was performed in March 2012 at the Lifecycle Engineering Solutions Center (LESC) of the Karlsruhe Institute of Technology (KIT). The main use case consisted of a car dashboard configuration tool with six variable design elements, each of them featuring three to four alternatives. These elements were constructed and implemented in Virtual Reality within an interdisciplinary team of one scientific researcher and 12 students near completion of their studies. Their fields of studies and roles as well as the overall development process corresponded to the methodology description in Section 4. The 21 participants were potential car purchasers of both sexes and different age groups, thus constituting a representative sample of the target group (Table 1). In order to assess the repeatability of emotional feedback using different methods, the same experiment was performed with each participant twice on different days.

The immersive environment (Figure 2) consisted of a three-wall passive stereoscopic projection (CAVE) with dimensions 4,5m x 2,6m x 1,9m, high resolution and optoelectronic ART head-tracking. For interaction purposes a single, simple selection gesture was implemented—a movement towards and away from the targeted object. The gesture was recognized using hand tracking with optoelectronic sensors and a simple pattern recognition algorithm.

The measurements of peripheral physiological parameters were performed with the mobile device NEXUS-32, which was attached to the participant's waist using a flexible belt. Following measurements were applied: electromyography of the zygomaticus major and the corrugator supercilii muscle activities (on face), blood volume pulse and electrodermal activity (on fingers). The cables which connect the electrodes to the NEXUS device were fixed appropriately on the participant's clothes. The captured physiological signals were sent to the computer via Bluetooth and were synchronized with the interaction log using a Network Time Protocol Server and a timestamp.

The experiment lasted about an hour per participant. Firstly, they had to fill a questionnaire on personal data, their experience with the product and with VR as well as on their current mood. After the electrodes were attached to the participant, an emotional calibration session based on the IAPS series was performed. Twelve blocks (of ten pictures each) were played to the participant on a PC monitor in a randomized order. Every picture was played for two seconds (i.e. 20 seconds per block), before and after each block a break of 20 seconds ("black screen") was settled. Each block corresponded either to an octant of the PAD model or to the neutral state.

The next task was to play memory game in the CAVE on a 4x4 matrix, with the goal of acquainting the participant to the implemented interaction. In this game the participant has to subsequently open two cards of the matrix with the selection gesture. If the items on both cards are same, then they remain open; otherwise they are closed. The goal is to eventually open all cards. No time limit was set for the solution of the game, so that it cannot give rise to a negative mood. The game was repeated twice in the first and three times in the second experiment.

The main use case consisted of the building of the best and worst configurations of all given possibilities using the selection gesture. In the first experiment the participant was first asked to get acquainted with all alternatives. Physiological data was gathered quasi-continuously (128 times per second) during the whole experiment. After having built the best and the worst configuration, the participant was asked to imagine that they have bought it and drive it for 30 seconds, subsequently describing its emotional effect using adjectives. Closed questions about the emotional effect of each alternative, based on a five-point Likert scale from "appealing (1)" to "non-appealing (5)", were answered immediately after the configuration process. A color preview was used as reminder of the alternative. The questions were not asked during the configuration, due to a pre-study showing that this procedure fragments the experiencing process too severely and triggers negative emotions. At the end, the participants answered 13 questions about the suitability of the applied technologies.

The captured data on the interaction steps and on customer

Element name	Repeatability rate	Spearman coeff.
Wheel-1	38%	0.79
Wheel-2	48%	0.57
Wheel-3	19%	0.55
Gear-1	38%	0.61
Gear-2	52%	0.77
Gear-3	48%	0.63
Pedal-1	29%	0.18
Pedal-2	33%	0.36
Pedal-3	43%	0.63
TexWood-1	52%	0.69
TexWood-2	48%	0.65
TexWood-3	48%	0.42
TexWood-4	33%	0.71
TexSurr-1	33%	0.49
TexSurr-2	57%	0.83
TexSurr-3	43%	0.48
TexFloor-1	62%	0.78
TexFloor-2	38%	0.62
TexFloor-3	48%	0.60
TexFloor-4	62%	0.76

Table 2: *Composition of the Test Group*

emotional feedback was evaluated off-line. Significant features from the gathered physiological data were extracted using Matlab. The subsequent recognition of emotions for single product variants was conducted using a neuronal network trained by data from the emotion calibration session. Statistical analyses were performed with the software SPSS Statistics. The results were eventually applied successfully to reduce the variant space.

6. Results

The study showed that the proposed methodology is coherent and successfully applicable. The main findings of the study regarding preferred solutions for interaction and emotion capturing are described here briefly. Simple gestures are suitable for interaction in VR for product evaluation purposes, because they are easily learnable. Figure 3 shows the average time needed for one memory game in the five played rounds (round 1 and 2 are from the first, round 3 to 5 from the second experiment). The participants got used to the implemented interaction after only two rounds, as seen by the insignificant variance in completion times for the remaining rounds, caused solely by coincidence factors. The comparison of the answers for all 20 alternatives for separate variable elements from both experiments showed that the overall repeatability was only 44% and that the same participant often gave contradictory answers. Table 2 shows that only six of the 20 alternatives feature answers with strong positive correlation (Spearman coefficient higher than 0.7). For one of the pedal sets this coefficient was only 0.18, which practically means arbitrary answering (characterized with Spearman correlation coefficient 0). This result shows clearly that cognitively mediated answers on questions regarding emotions falsify the emotions significantly. The participants feel forced to give answers, although they often cannot quantify their impressions. As a result, they often give unreliable, ambiguous and arbitrary feedback. After classifying the Kansei adjectives into synonym categories, the number of mentions of each category was determined. Table 3 shows the top five adjective categories describing the individually best configurations of both experiments. The most important Kansei adjectives were reproduced fairly well – three of the five top categories in both experiments are repeating. However, because of the unlimited freedom of choosing adjectives and thus the variety of categories, the overall repeatability rate of a mentioned category from the first experiment in the second one was only 41%. Customers judge both design (e.g. "beautiful") and functional (e.g. "comfortable") properties of products at least partially emotionally, allowing both designers and engineers to participate at the creation of emotion customer value. It can be concluded that Kansei adjectives describe the major emotional effects of appealing products on a test group with satisfying repeatability. The disadvantage of the freedom of expression is the huge possible variety and hence the difficult statistical analysis of the results.

Experiment 1	Experiment 2
Classical: 5/21	Beautiful: 6/21
Comfortable: 5:21	Pleasant: 6/21
Beautiful: 5/21	Comfortable: 5/21
Noble: 4/21	Harmonic: 5/21
Modern: 4/21	Noble: 4/21

Table 3: *Top five Kansei adjective categories for the individually best configurations in the study*

The averaged activity of the zygomaticus major muscle was sufficient to recognize the valence of an emotion in 67% of the studied cases. On the contrary, the activity of the corrugator supercilii was found to be an unreliable parameter, mainly due to the unnatural movements of this muscle when wearing 3D stereoscopic glasses. The overall rate of emotion recognition, using all measured data from the car dashboard configuration use case and a neuronal network classification trained by data from the emotion calibration session, was about 60%. An important condition for the reliability of results was identified – the participant has to spend at least five seconds to experience one product variant. These results show that peripheral physiological measurements can be successfully applied for capturing customer feedback on virtual products. They are more reliable than questioning methods. The main reasons for the good repeatability are the lack of cognitive mediation during the measurements and the exclusion of opportunistic interference to a large extent. Only one of 21 participants was reserved about their applica-

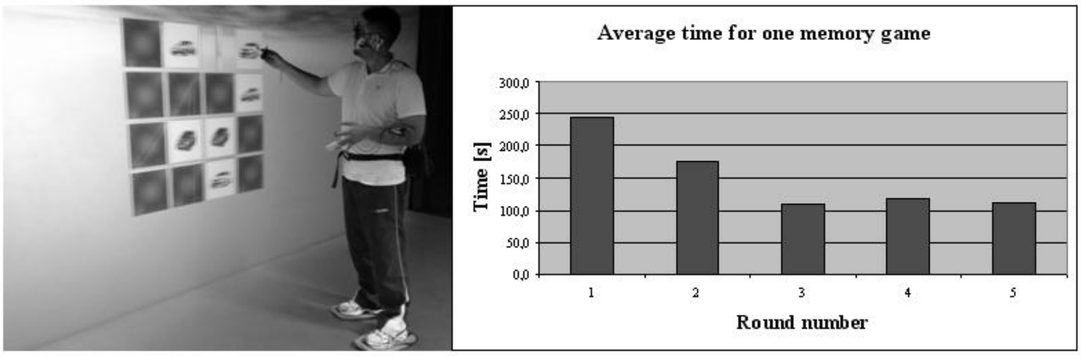

Figure 3: *Memory game (left) and the average playing time in each round (right)*

bility in early stages of product development. Ethically unacceptable is the application of this method in the sales stage. Disadvantageous is the relatively high intensity of personal and technical resources needed to perform the study.

7. Conclusion

This paper presents a six-step methodology that integrates the VR technology with emotion recognition technologies in order to enable reliable emotional customer feedback on virtual products in the early conceptual stages of product development. Immersive VR environments offer possibilities for full-sized, context-faithful representation of virtual products and their usage, with the customer as agent in the virtual world. In this way customers' imagination and hence more natural emotional feedback is promoted. Emotion capturing has to be scientifically founded and carefully performed, because of numerous falsification risks. Crucial conditions for reliable emotion capturing are individual emotional calibration using standardized methods and implementation of easily learnable interaction in VR, which is performed routinely and does not influence the customer's emotions. Peripheral physiological measurements were found to be more promising with regards to the reliability (repeatability rate) of results than closed questions. The common approach to describe emotions by cognitive evaluation on Likert scales appears to be not reliable. The presented methodology is coherent and achieves synergies among experts of different areas and between experts and customers. Its further development steps are the analysis of its organizational acceptance and the assurance of serial application.

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