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OPTIMIZING THE EVALUATION OF EYE TRACKING DATA TO VALIDATE REQUIREMENTS IN VIRTUAL SPACE TO IMPROVE CUSTOMER SATISFACTION

Christian ESSER, Robert REFFLINGHAUS

Abstract: *This paper describes a concept to support the validation of customer requirements in the early phases of the product development process. Change requests or product malfunctions therefore can be identified earlier and resolved more cost-effectively. The advantages of the early requirements validation will be discussed. The differences between real prototypes and virtual prototypes will be discussed and elaborated on. The special features of eye tracking in stereoscopic virtual space will be shown. A small study will be presented, which helps to analyze the perception in virtual space. Thereby it will be dealt with the planning, implementation and evaluation. In addition, measures for optimizing data filtering are presented and explained exemplarily.*

Key words: *Customer requirements, customer satisfaction, product development, eye tracking, data evaluation, virtual prototype*

1. INTRODUCTION

As part of the trend towards increasingly customer-specific products, quality management must also adapt to the new circumstances. The quality of a product is seen as the most important factor influencing market success [1]. The fulfilment of customer requirements plays an overriding role in this trend [2]. Continuous progress in the field of virtual prototypes makes it possible to interact with customers early in the product development process and thus analyze the significance of various product features. A potential tool to record these interactions with the virtual product for further investigation is eye tracking. This makes it possible to record the eye movement and identify focal points of interest. Due to its high complexity, eye tracking data on three-dimensional objects is usually evaluated manually. The motivation for this work is to develop a procedure for a manual evaluation of eye tracking scene videos, which should make it possible to identify focal points of interest of the customers under consideration of different assumptions. This data should enable later users to draw conclusions about the significance of various quality characteristics.

2. STATE OF THE ART

A key factor is to involve the customer in the product development to produce high-quality products. In the early stages of the product development process the possibility to take influence on the product is very large (see figure 1). That is why it is important to involve customers in the early phases. However, the customer requirements can currently be validated mostly not until real prototypes are available [3]. This takes place at a time when the influence on the final product is lower. Virtual product presentation, offers the possibility to yet simulate first initial findings on the product features and functions. Virtual prototypes describe digital mock-ups and expand these to functions and physical properties. It is possible to carry out analysis and simulations with the virtual prototypes, which are comparable to those of real prototypes [4]. Due to the function support the virtual prototypes allow a real-time controlled interaction by test persons [5]. The necessary data for the creation of virtual prototypes are already qualitatively developed in the design phase and thus are available at an early stage. If it is possible to use the virtual prototype to check the customer requirements, this information would be evaluated in product development process much earlier.

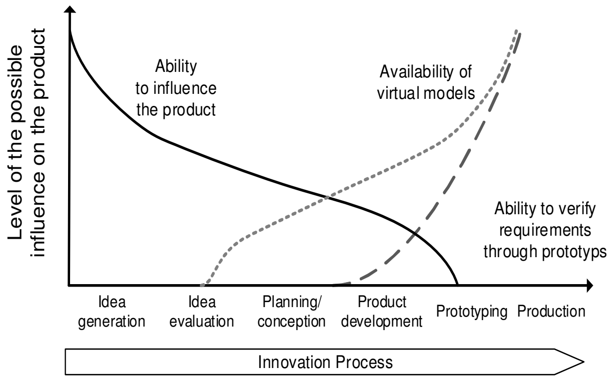

Fig. 1. Optimization potential with early requirements validation in the innovation process [3]

The final product design has not yet been fully developed in the concept phase. Nevertheless, the customer can already give valuable feedback with the available information. By creation of virtual prototypes it must be taken into account that mainly the visual perception of the test person can be addressed. Although the visual sense is the most important sense in the human perception [6], it restricts the virtual prototype testing. Product features can only be described optically. For successful use of virtual prototypes uniform design guidelines must be also followed, in order to improve the close-to-reality models [7]. Then designers, engineers and end users could use a virtual prototype for evaluating the aesthetic quality, its functions and its usability aspects.

A solution to identify the customer requirements virtually, could be found in the combination of different methods and tools. Below existing approaches are explained which cover several areas of the problem.

The three dimensional virtual reality (3D VR), in which stereoscopic three-dimensional models can be shown, are already used in big companies for product development [8]. By means of the depth effect and a high interaction radius through a simulation of the product model in real-time the degree of immersion increases. The high degree of immersion of such interactive systems allows the user a very accurate perception of the product model represented and a good understanding of product features and functions of virtual prototypes. Up to now tools are missing for the evaluation of main areas of interest of customers in the three-dimensional virtual space. About 80% of human perception takes place via the visual sense. Research results have shown that the visual perception and eye-movement strongly correlate with each other [6]. Eye tracking allows to record the eye movements of test persons. Thereby recorded fixations, saccades and binocular movements can be evaluated. Two-dimensional (2D) monocular eye trackers already allow to analyze the focus of attention of the customer [9], [10]. By measuring the fixation points (particular sighted point in space), fixation duration, saccade (short jumps from one fixation to the next) and the fixation order, conclusions about the attentional processes of the subjects can be drawn [11].

Qualitative representations of results are gazeplots, which depict the fixations of their duration and saccades. An excerpt from such a gaze replay can be found in the following figure 2. This should give an impression about the representation of eye tracking data on gazeplot basis and illustrate the integration of this representation form into a scene video. Only plots 83 to 90 are shown in this section, which increases the clarity.

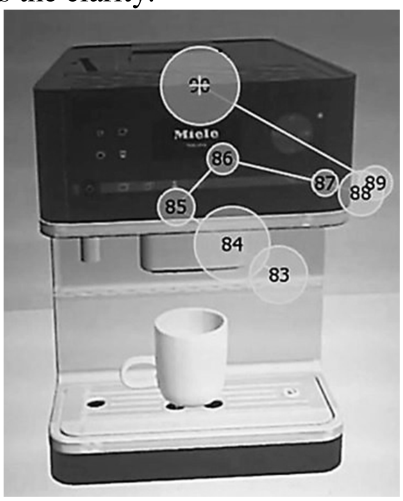

Fig. 2. Gazeplot created with SMI BeeGaze

A gazeplot offers the possibility to display the fixations, their duration and the saccades together [12]. Fixations are represented as circles and saccades as connecting lines between the circles. The size of the circles provides information about the duration of a fixation. The order of the connections between the different fixations can be determined. The application of gazeplots in three-dimensional virtual reality, however, is sometimes very difficult.

This is due to the fact that the head position or orientation in virtual reality must always be taken into account in the evaluation. This also makes it more difficult to display the results graphically [13]. A display of all 90 plots would make the evaluation of the image considerably more difficult, which illustrates the already described disadvantage of the display on gazeplot basis. Due to the interaction with the virtual prototype, the gazeplot cloud can only be visualized for a short time and changes constantly via the moving virtual prototype.

Areas of Interest (AOI) are a tool for evaluating eye tracking data, also known as area analysis. Areas within the field of vision are defined beforehand and the duration or number of fixations within this area is determined. A disadvantage of this tool is that the AOI are static objects. As a result, dynamic objects cannot simply be automatically taken into account in the evaluation [14].

However, a quantitative allocation can be achieved via manual video evaluation of gazeplot images.

Furthermore the three-dimensional (3D) representation is still a challenge for the evaluation of binocular eye trackers. With the third dimension, the stimulus is extended by a new level, the depth. Furthermore, eye tracking studies prove that the human perception changes with increasing closeness to reality. The scenery is looked at differently, the view in the 3D environment is less focused than on a 2D screen, which is also reflected on the heat map in figure 3. A larger area is scanned with the eyes, but with significantly shorter fixation times. In the 3D environment more easily shaded areas are found, while in the 2D environment the intensive areas dominate. Hence, it can be seen that the fixations are more intense and longer on the 2D screen [15]. The reason is that in the 3D environment significantly more eye movements take place, because the eyes fixate more on objects than in 2D. By the depth effect objects that are usually in the background and are usually ignored as far as possible, occur in the attention span of the viewer. The number of individual fixation points becomes larger, the fixation duration less. This fact must be taken into account in customer studies.

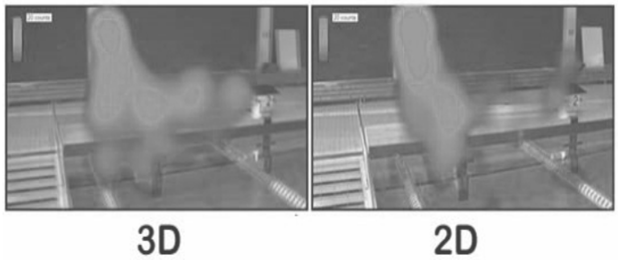

Fig. 3. Perception in 3D (left) und 2D (right) [15]

Eye tracking studies alone, without a subsequent detailed interpretation analysis cannot explain why the test person is focusing on a particular screen element or not. The method of eye tracking is limited, it does not give an answer to the real intention of a viewer's gaze. [16] Holmqvist et al. describe a possibility of cross-validating data, with which the various advantages of individual methods for eye tracking analysis are combined. This should make the results of the analysis more meaningful. In the context of cross-validating, various tools are described as auxiliaries. Among them are several behavioral measures as reaction times, electroencephalography (EEG), galvanic skin response and similar. Furthermore, verbal data analysis is also recommended, describing the most commonly used method for knowledge elicitation in combination with eye tracking [16].

Verbal data analysis differs essentially in the time at which they are used: concurrently or retrospectively. Concurrent think aloud have the advantage of a direct description and evaluation of the currently seen. However, the act of talking has a negative influence on the eye tracking analysis itself. The participant quiver or move enough that the recordings of eye movements will be less precise [16]. In addition, it can be assumed that cognitive performance has an influence on visual perception.

In the retrospective think aloud, the think aloud is only recorded after the eye tracking examination has been completed. This avoids inaccuracies in the handling of eye tracking.

However, decoupling the think aloud from the study can lead to some details being lost from memory [16]. Therefore it is necessary to optimize the data evaluation in order to be able to make a comparable statement about the over-enthusiasm of eye tracking in virtual and real space.

3. DERIVATION OF OPTIMIZATION MEASURES

Due to the described requirement for eye tracking data evaluation, it is necessary to introduce optimization measures.

The data evaluation is also placed on the basis of the described complex evaluation of the eye tracking data in 3D space partially manually. The evaluation of the AOI in connection with the results of the retrospective think aloud is carried out by means of a manual evaluation of scene videos. In the simplest case, the fixation points and their fixation time are evaluated. Optimization guidelines allow a clearly more precise evaluation.

According to studies by Chen and Chen [17], the significance of an area for the test person correlates with the number of fixations and the duration of these on the area. Consequently, it is assumed here that for a comparison of quality function deployment (QFD) weighted characteristics with the recorded eye tracking data, the number and duration of fixations can be used as a criterion for the significance of quality characteristics for the customer.

In this context, fixation refers to the stationary stabilization of a fixation point over a temporal retention period. Very short fixations indicate an unconscious perception. The duration of fixations increases with the complexity of a task. Thus, the duration of a fixation can be used to interpret the degree of difficulty of a task for the test person and the fixations themselves can be used as a measure for the duration of information processing. However, it is difficult to make a generally valid statement about threshold values of fixation durations, which are independent of the object considered and the difficulty of the task to be accomplished [18]. A threshold for conscious fixations, varies in the different studies. For this work, a value of 500 ms is determined on the basis of Libet et al. [19]. This value is used as the first filter for data evaluation and makes the evaluation effort more precise and reduces the complexity of the recorded data.

In addition to the duration of individual fixations, other studies have shown that the memory performance of test persons increases with the number of fixations per object. This significantly increases the recognition of objects from the second fixation per object [20]. The second filter only considers at least two consecutive fixations falling on an AOI in the evaluation.

Further, human vision can be divided into focal and ambient vision. Simplified, focal vision is of greater importance for a conscious perception of objects and consequently a comparison of QFD weighted characteristics. Thus, fixations are of greater importance for an evaluation, which fall within the range of focal vision of the previous fixation. A simplification guideline to include this assumption in an evaluation is to consider only the number of fixations after saccades less than 4° [21].

Another way of taking the assumption described above into account in the evaluation is to normalize the fixation times over the saccade amplitude. Such a similar combination of fixations and saccades is also carried out in the generation of so-called "attention landscapes" [21]. An evaluation of eye tracking data should be done according to this approach by summing the quotients of fixation time and the amplitude of the following saccade. This allows a disproportionate consideration of the fixations of focal vision in the evaluation.

Based on the simplification guidelines described in the previous section, the eye tracking data can be prepared for a final interpretation of the results. The previously created link between recorded fixations and defined AOI essentially allows the simplification guidelines to be summarized as follows:

1. absolute number of fixations per AOI
2. total duration of fixations per AOI
3. number of fixations > 500 ms per AOI
4. number of fixations per AOI after more than one consecutive fixation falls on the AOI
5. number of fixations per AOI whose saccade amplitude is < 4°

6. sum of the quotients of fixation time and saccade amplitude per AOI

4. CASE STUDY

The motivation of this study is to increase the informative value of eye tracking data. To this end, a small study was carried out. The eye tracking study is based on a pre-defined scheme that aims to compare eye tracking analysis on virtual and real prototypes. For this study standards need to be developed for comparable results, which can be described as follows.

Set-up of the product model (virtual prototype):

The aim is to assure that the general appearance of the virtual product model matches the real product. Size conditions must be adapted 1:1 in order to ensure a high immersion. Colors must match so that there cannot be unwanted distractions. Functions must be deposited and able to be used interactively in real time. When selecting the product it is important to make sure that this will not pose problems in a 100" power wall. A fully automatic coffee machine meets these requirements and can be well simulated. The object of investigation is a fully automatic coffee machine CM 6300 from Miele. This was extensively prepared on the basis of CAD data and equipped with functions. This enabled real-time interaction via various input devices. The operating concept varies between models and can be used for this study. The virtual reality technology serves as a tool to carry out experiments as well as exploratory tests and to collect data [22]. Repeatable, valid data, in order to gain connections and insights, serve to reduce the difficulties of understanding within the product development process. They therefore promote risk minimization within development.

Set-up of the test environment:

The virtual test environments should match the real test environment, potential distractions must be eliminated. The input devices to interact with the virtual prototypes play an important role. Rademacher describes an attribution of input devices to the specification of VR-work systems. Here, the power wall creates a highly collaborative environment, a joystick/gamepad for intuitive input is recommended [23]. A gesture control could make input more intuitive. For the planned series of tests a gamepad is used as many test persons have previous experience with this input device.

Choice of the test persons:

The people need to be clustered according to their previous knowledge. A different level of experience of the users with the VR can lead to various scene evaluation. Initial tests have shown that the experience of using a gamepad allows a completely different interaction with the virtual prototypes and thus provokes different results. Experience in the use of S3D models also significantly contributes to the acceptance in handling virtual prototypes. For clustering the test persons in advance short questionnaires are issued, in which the handling of input devices and the experiences are requested using virtual reality. On the other hand, the demands of the ISO 16355 must be considered to the customer selection of QFD projects.

In the ISO 16355-2:2016 various methods and tools are presented, how customers and their voice can be determined.

At the beginning of this study, an initial QFD was performed. For this a target group analysis was carried out and the requirements of 26 people were recorded via an online questionnaire. 20 male and 6 female respondents completed the questionnaire. The average age of the respondents was 26.4 years. All respondents indicated that they occasionally drink coffee. 15 essential customer requirements of the highest order could be generated and flowed into the QFD. In order to set the right priorities in development, these customer requirements had to be weighted. This was done using a scale query from the participants. The weighting resulted in a differentiated evaluation of the requirements. The weighted customer requirements form the basis for the further assignment of priorities in the entire QFD process. The individual customer requirements were evaluated on a five-tier scale. The higher the number, the more important the requirement was to the participant. Product characteristics were derived from the weighted customer requirements. Each customer requirement was fulfilled by at least one characteristic. A total of 13 product features were developed. These were transferred to the House of Quality and the relationship matrix could be filled in. The better the feature meets the customer's requirements, the higher is the rating at the intersection. With the weighting of customer requirements and the evaluated interrelationships (in the relationship matrix), a ranking list of the most important characteristics could be created.

The most important optically perceptible features could be taken from this ranking list and assigned to the virtual prototype (figure 4).

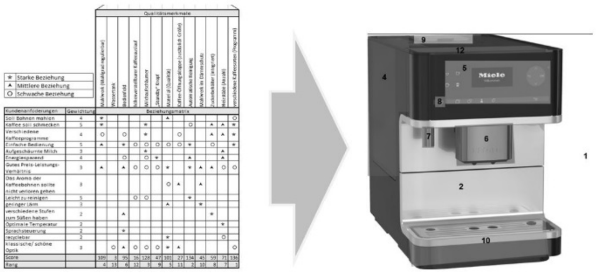

Fig. 4. Deriving the AOI from the ranking of product features of a HOQ

Assessment flow: In the evaluation of the tests, a two-stage approach is recommended. Here, the eye tracking data are recorded and stored. Following the tests, the test persons face their recorded eye tracking data. The test person has the opportunity to comment on his intentions during the test and equalize this with the recorded aspects. Thus, deviations of the eye movement can be determined. Thereby the flow of the core study can be described as follows:

1. Introduction of the study. Here the aim of the study is presented and the participants are informed about the process. Data protection is also discussed. Sociodemographic questionnaires are filled in to classify the participants. The affinity for technology and previous experience in dealing with virtual reality is also questioned. Main study: In this step, the main study is carried out using a prototype. Users are confronted with standard tasks (1 min. free handling of the model (explore the device independently); 2 min. for tasks in handling the prototyp; 1-2 min. for open questions that are solved in cooperation). While the participant tries to work on the task, eye tracking, audio and screen recordings are recorded and supplemented with short notes. These help to clarify questions in the following meeting and to understand the user's expectations.

2. Retrospective think aloud: Individual conspicuous features discovered by eye tracking should be tracked and interpreted by the participant. It is also possible to question user evaluations and to specify special system components that are linked to the requirements in detail. A data collection with a partially structured interview can generate additional information. The basic requirements for this step are scene videos with gazeplots or / and an evaluation of the AOIs.

This standardized procedure ensures the same basis for all analysis. The comparability of the determined data is thus ensured.

The eye tracking study on the presented product took place in a completely darkened room to avoid external disturbances. To record the eye tracking data, an eye tracking system from Senso Motoric Instruments GmbH (SMI) was used, which works according to the cornea reflex method. The data was evaluated using BeeGaze® software, also developed by SMI. This made it possible to display the eye tracking data in the form of a gaze replay and to output the recorded fixations with their corresponding duration and spatial coordinates as raw data in tabular form. The study was conducted with seven male and three female test persons.

After performing the eye tracking study, the recorded scene videos had a length of five to six minutes at approximately 600 to 700 recorded fixations. In the first step, the evaluation was performed manually, based on the number of fixation points per AOI and their summed duration.

During the manual evaluation of the recorded scene videos, the absolute number of fixations per quality feature that lasted longer than 500 ms was counted. The limitation to fixations longer than 500 ms was chosen in order to keep the evaluation effort by manual counting within a manageable range. To further simplify the manual evaluation, it was assumed that the number of fixations per quality characteristic correlates directly with the importance of the quality characteristic for the test persons.

The result of the eye tracking study was the ranking of the importance of the quality features of the fully automatic coffee maker listed in the following table 1. In the retrospective think aloud, the results and their motives could be questioned and analyzed. In addition, further requirements for characteristics could be derived from the retrospective think aloud.

Table 1.

Results of the classic eye tracking analysis

Characteristics	AOI	rank
Envireonment in VR	1	2
Area outside the scene	2	3
Grinder	3	6
Water tank	4	5
Control panel	5	1
Coffee spout	6	8
Milk frother	7	12
Standby button	8	10
Caffee beans flap	9	4
Drip tray	10	9
Maintenace flap	11	11
Cup heating	12	7

In the second step, the evaluation was carried out taking into account the simplification guidelines presented. Table 2 shows the changes in area of interests due to the introduction of the different stages.

Table 2.

Excerpt from the study evaluation

AO I Nr.	stage 1 μ	stage 2 μ	Stage 3 μ	stage 4 μ	stage 5 μ	stage 6 μ
1	15%	16%	15%	13%	12%	11%
2	15%	13%	15%	12%	13%	13%
3	5%	6%	4%	7%	3%	5%
4	7%	6%	4%	9%	7%	6%
5	33%	35%	38%	38%	42%	42%
6	4%	4%	5%	2%	4%	3%
7	1%	1%	1%	1%	1%	1%
8	2%	3%	3%	1%	3%	5%
9	8%	7%	7%	8%	8%	7%
10	4%	3%	4%	4%	3%	2%
11	2%	2%	2%	2%	1%	1%
12	5%	4%	3%	3%	4%	4%

The percentage significance of the various AOIs in table 2, for example, shows across all criteria that the test persons paid the most attention to the control panel of the fully automatic coffee machine (AOI 5). In addition, a large proportion of the fixations fell on the offsite (AOI 1), which does not illustrate any information.

In the following diagram (figure 5) the precision of the individual stages is presented graphically. The left bar describes the mean value of the percentage meaning of the control panel (AOI 5). The right bar describes the percentage meaning of the offside (AOI 1). The individual stages show the concretization/decrease of the significance of the introduced measures.

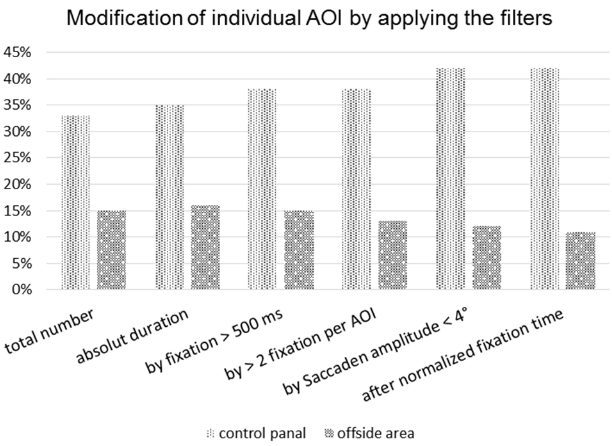

Fig. 5. Presentation of the effects of the individual stages of improvement

The increase in the importance of the AOI 5 (control panel) and the decline of the AOI 1 (environment) can be explained by the conscious perception of the control panel as a control element and the unconscious perception of the insignificant environment. By introducing the threshold value of 500 ms and the necessary number of two fixations per AOI, the conscious perceptions could be concretized. The unconscious or unintentional part could thus be reduced. An evaluation taking into account the saccade amplitude for the stages 5 and 6 even leads to an increase to 42%.

This suggests the assumption that the proportion of fixations deliberately directed to the control panel by test persons is significantly larger than taking into account the absolute number or duration of fixations after stages 1 and 2; furthermore, the results from Table 1 allow the assumption that by normalizing the fixation duration over the saccade amplitude after stage 6, the significance of smaller AOI increases. This is shown by the example of the "Standby" button (AOI 8). Its importance is highest after stage 6, which is probably due to the fact that frequent saccades of small amplitudes occur in small areas. This weighting according to stage 6 can be of great importance, since it can be assumed that the number of fixations on an AOI depends on its size, which may be independent of the significance of this quality feature.

With these filtered data it is possible to obtain more meaningful results from the AOI evaluation. If this data is returned to a QFD, it can be specified and the characteristic weighting can be specified. Development decisions are thus influenced in the direction of customer interest. In order to enable an interpretation of the main areas of interest, the characteristics concerned must be analyzed in a retrospective think aloud. The characteristic value (positive, negative) of the characteristics can be determined from the explanation of the customer view. In addition, the preferred characteristics can also be analyzed in a targeted manner. This results in a specification of the customer requirements and has the potential to expand and rebalance the customer requirement set. An end product that reflects customer requirements is the positive result of this approach.

The findings developed here must be further investigated in a broad study. In order to make the evaluation effort manageable, an automated AOI evaluation in virtual space is currently being worked on.

5. CONCLUSION

The recorded data of the eye tracking study described here were evaluated in the form of scene videos and corresponding raw data tables.

The evaluation was realized by a range analysis with previously defined AOI, whereby the AOI correspond to previously derived product characteristics.

Against the background of the assumption that the significance of a characteristic is reflected in the number or duration of fixations per AOI, the percentage significance of these characteristics for the test persons was determined. On the basis of various simplification guidelines, it could be shown that this percentage importance varies in some cases considerably.

In this work it is succeeded in carrying out the manual evaluation of eye tracking scene videos using a systematic schematic and summarizing them to a clear result.

The decisive question that arose was to what extent the results according to the various underlying simplification guidelines reflect the importance of quality characteristics for the customer.

Customer surveys will continue to be necessary in the future to analyze the significance of individual characteristics and the relevant customer requirements.

However, the percentage significance of characteristics determined according to the procedure in this work can be used to systematically and purposefully design a subsequent customer survey.

In addition, there is the possibility of expanding and specifying the initial QFD with the new findings.

More customer-oriented product development and the resulting increase in customer satisfaction could go hand in hand with this.

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Optimizarea evaluării datelor de urmărire a ochilor pentru a valida cerințele în spațiul virtual pentru a îmbunătăți satisfacția clienților

Rezumat: Acest articol descrie un concept care să sprijine validarea cerințelor clienților în fazele timpurii ale procesului de dezvoltare a produsului. De aceea, cerințele de modificare sau defecțiunile produsului pot fi identificate mai devreme și rezolvate mai eficient din punct de vedere al costurilor. Avantajele validării cerințelor timpurii vor fi discutate. Diferențele dintre prototipurile reale și prototipurile virtuale vor fi discutate și elaborate. Vor fi prezentate caracteristicile speciale ale urmăririi ochilor în spațiul virtual stereoscopic. Va fi prezentat un mic studiu, care vă ajută să analizați percepția în spațiul virtual. Prin aceasta se va aborda planificarea, implementarea și evaluarea. În plus, măsurile de optimizare a filtrării datelor sunt prezentate și explicate în mod exemplar.

Christian ESSER, University of Kassel, esser@uni-kassel.de
Robert REFFLINGHAUS, University of Kassel, Refflinghaus@uni-kassel.de