A Quality of Experience Model for Haptic User Interfaces

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ABSTRACT

Multimedia systems and applications have recently started to integrate the sense of touch and force feedback in the human-computer interaction. Surprisingly, measuring the quality of experience when haptic modality is incorporated in a graphical user interface has received limited attention from the research community. In this paper, we propose a taxonomy for measuring the quality of experience of a haptic user interface (HUI) applications. Furthermore, the taxonomy is modeled using a mathematical model. Finally, the proposed model is evaluated using two HUI-based applications: the haptic learning system and the haptic enabled UML CASE tool. The performance evaluation demonstrated that the proposed model is capable of reflecting the user estimation of the applications.

Categories and Subject Descriptors

C.4 [Computers System Organization]: Performance of Systems – *Reliability, availability, and serviceability.*

H.1.2 [Models and Principles]: User/Machine Systems - *Human factors, Software psychology.*

General Terms

Measurement, Performance, Human Factors, Reliability, Standardization.

Keywords

Quality of Experience, Haptic User Interface, Haptic Perception.

1. INTRODUCTION

Haptics technology has changed the way humans interact with computers. Incorporating the sense of touch into virtual environments has opened a new trajectory of interactive applications ranging from medical simulations and rehabilitation to more realistic video games. Gradually more and more applications will utilize haptic interfaces and they will be geared toward the three modals feedback namely: visual, auditory, and touch feedback. The advantages of haptics audio and video environments to the user are more realism, more excitement, and better manipulation of objects. Thus it is not far away that we are even going to see haptics e-commerce applications over the Internet. [1]

Although the advantages of haptics virtual reality applications are clear, it is still not vividly determined how users experience those applications. There is a lack of measurement of these advantages objectively through a concrete evaluation model. Quality of Experience (QoE) for Haptic Virtual Environments is an evolving research topic concerned in evaluating virtual environments. The measured QoE is an indicator of the advantages of a certain environment and the amount of involvement of a user. [2]

QoE is more than just assessing the Quality of Service (QoS) an application provides to users. While QoS is part of the assessment, whether it is jitter and delay of the network or synchronization of haptics and graphics feedback, there are still other parameters to consider such as ease of usage, rendering quality, and measurement of fatigue. These added parameters along these lines are subjective and describe the 'experience' of the user. Both the QoS and the users' experience compose the overall QoE which in turn will reflect the quality and value of haptic virtual applications. [3]

The ultimate QoE is total immersion in which users are completely immersed in a virtual world to the extent that it can not be differentiated from the physical world. As total immersion is still beyond reach, we have to rely on QoE measurements to assess an environment. Measuring QoE is a challenging task and researchers have been trying several methods to come up with an ultimate approach but the diversity and complexity of virtual environments hindered the progress in that field. [2]

In this paper, we propose comprehensive taxonomy for Quality of Experience (QoE) evaluation metrics associated with haptic-based virtual environments. This taxonomy includes all the related parameters that are necessary to assess and test the advantage/disadvantages of a haptics application. We also propose a simple mathematic model for evaluating the QoE of the application. The purpose of the mathematical model is to quantify and measure the QoE parameters objectively instead of having subjective evaluation. Finally we present the results from deploying our QoE model and evaluating this model by testing it with two haptic-based applications.

For the evaluation part we chose two applications that have a haptic-based graphical user interface. At this point we would like to coin the term HUI (Haptic-based User Interface) to refer to applications that utilize haptic interfaces instead of a mouse to manipulate the user interface. In particular, we chose HUI applications to deploy our QoE model because we wanted to focus solely on the haptics experience of the application apart from the video and audio feedback. Even though our taxonomy is comprehensive but at the same time it is customizable and suits any type of application whether it is a HUI application or an immersive virtual reality application.

The rest of the paper is organized as follows. Section 2 reviews the related work in the field of QoE for virtual reality applications. In Section 3, we present our taxonomy for QoE parameters including the complete charts and our rationale behind that taxonomy. Our mathematical model that is based on the taxonomy is proposed in Section 4. In Section 5 we describe the

HUI applications to be evaluated through our QoE model and the analysis of that evaluation. Finally we conclude this paper and state the future work in Section 6.

2. Related Work

There has been some work done in evaluating virtual environments. The evaluation methods and the aspects to be evaluated vary depending on the type of the application and the parameters to be evaluated. In [4], Basdogan et. Al. conducted studies to evaluate the haptic feedback role in collaborative human-human and human-machine interactions in shared virtual environments (SVEs). The evaluation consisted of measurement of response variables as well as questionnaire to the users undergoing the experiment. Another approach to measure haptic benefits is given in [5]. The authors measure physical parameters generated by the haptic device directly in order to assess the quality of the application. They suggest that this is a complementary approach to conducting a statistical survey after users test the application. Some of the parameters that they chose to include in their physical survey are gesture position and gesture velocity.

A unique approach that was suggested in [2] is to use physiological measures to determine the QoE of virtual reality applications. Taking stress as an example, there are direct measurements that can indicate if the user is stressed under prolonged exposure to the virtual environment. Under stress, the sympathetic nervous system is activated and blood volume, heart rate, and respiration rate all increase. Ramsey [6] argue that measuring those symptoms directly is more effective than a questionnaire due to three limitations

1. people are mentally aware to their internal state when under the same circumstances they would normally not.
2. people might not understand the implication of the response in the questionnaire
3. people may not wish to report feeling any symptoms

3. Quality of Experience (QoE) Model

In this section we describe our QoE model and the taxonomy we used to organize the different parameters. Our initial taxonomy was based on subjective vs. objective metrics. As such, we divided the parameters into two groups: ones that can be measured directly from the application such as forces and delay, and the other group that has to be deduced by other means such as user questionnaire and behavior; for instance intuition. However we felt that in such a model the taxonomy should stem from the core definition of QoE. Hence we based our top organization into two parts: QoS and User Experience parameters. Surveying the literature and exploring what User Experience is composed of we further subdivided this category into four parts: Perception Measures, Rendering Quality, Physiological Measures, and Psychological Measures. This higher level organization, shown in Figure 1, reflect an apparent taxonomy for Virtual Reality applications evaluator, and at the same time is more customizable depending on the parameters needed for the evaluation. As an example, developers wishing to evaluate only the QoS of the application can disregard the User Experience parameters.

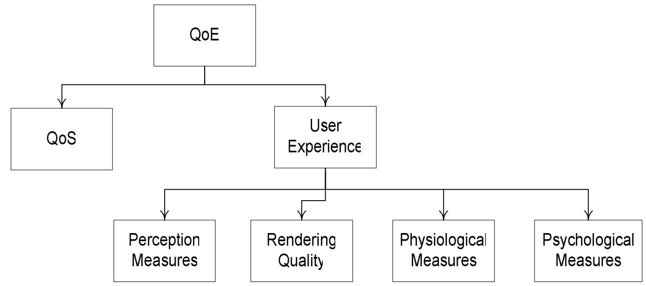

Figure 1. Higher level organization of QoE model

3.1 Quality of Service (QoS) Parameters

QoS parameters insure the smooth flow of the application for the user or in certain cases the customer. Most parameters are standard for any networked application but looking at Table 1 we can notice that synchronization is divided into two parts: network synchronization which is common to network applications and media synchronization which is specific to the multimodal side of virtual environments. We represent the QoS parameters with a table instead of a chart as most parameters have only one depth and no subcategories.

Table 1. Quality of Service Parameters

Response Time	
Latency/Delay	
Price	
Privacy	
Security	
Availability	
Bandwidth/Throughput	
Synchronization :	
	Network Synchronization (CVE)
	Media Synchronization (intra-modal)
Jitter	
Reliability	
Error	
	Magnitude
	Frequency
Safety	

3.2 User Experience

The second part that constitutes the definition of QoE is the User Experience. This is an important evaluation category for the overall quality of the application. Even if the application possessed excellent QoS parameters still users might feel that the application is not up to their standard for some reason. The application might not be exciting enough, easy to use, or causes dizziness which is referred to as cybersickness.

3.2.1 Perception Measures

We first begin by considering the first sub-category of User Experience which is Perception Measures. As depicted in Figure 2, perception measures mirror how the user perceives the application. This is a user-centric category, and could be unique for every user. Some users may get tired from the application, while others may feel relaxed. Some might feel the effect of collaboration in a collaborative virtual environment (CVE) while others might need more stimuli. Each user may have a certain set of preferences and modality choice.

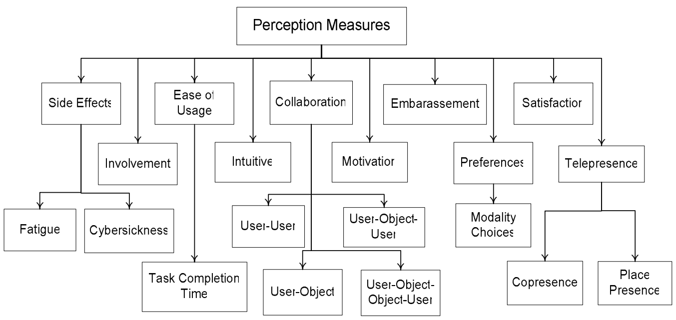

Figure 2. Perception Measures Parameters

Another point to consider is the fact that there are different levels of experience among users. While a certain group of users could be very experienced with virtual reality applications and very dexterous using haptic devices, others may be novice users and less skillful. This variation in the level of experience will cause users to have different perception regarding the application. When evaluating a HAVE application it is essential to include different categories of users and to insure that the application suits a wide range of audience.

3.2.2 Rendering Quality

The second part of User Experience is the Rendering Quality which is the quality of the three major modalities in virtual reality application, namely: graphics, audio, and haptics.

In this category each modality is evaluated separately first and then how these modalities blend and mix are evaluated. As can be seen in Figure 3, there is an emphasis on haptics modality as it is the newest modality to be introduced in VE applications, and it has very stringent requirements in terms of feedback loops which might affect the stability and transparency of the application.

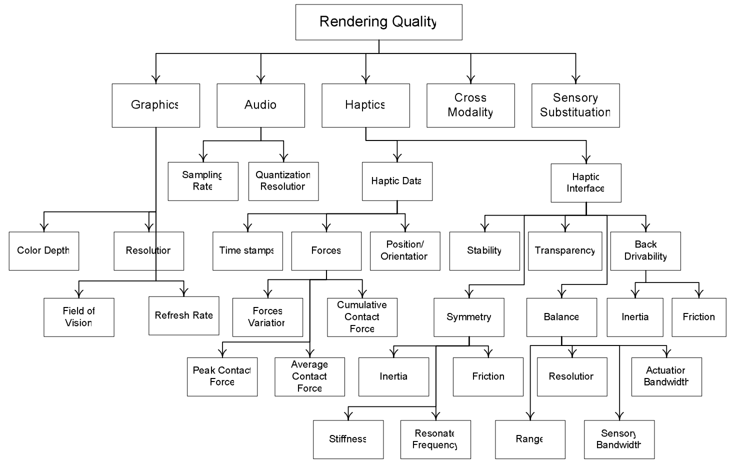

Figure 3. Rendering Quality Parameters

3.2.3 Physiological Measures

The third sub-category of User Experience is Physiological Measures. As the name indicates, these are biological parameters measured directly through users while they are using the application. These parameters reflect the status of users and determine directly factors such as cybersickness, stress, and brain activity [2].

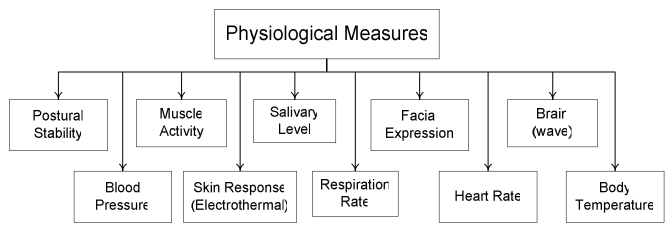

Figure 4. Physiological Measures Parameters

3.2.4 Psychological Measures

The last sub-category of User Experience is Psychological Measures. Unlike the Physiological Measures, Psychological Measures reflect the status of the user through observation but not direct measurements. Observation can asses the psychological behavior of users, such as stress, without hindering the user movements by including measuring devices. Psychological Measures are displayed in Figure 5.

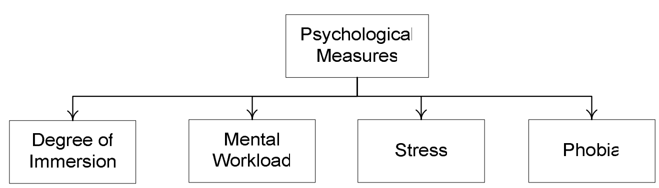

Figure 5- Psychological Measures Parameters

4. Mathematical Model

The Quality of Experience (QoE) is computed as the weighed linear combination of the Quality of Service (QoS) and User Experience (UE) for a particular haptic user interface, as follows:

$$QoE = \zeta \times QoS + (1-\zeta) \times UE \qquad (1)$$

Where

$$QoS = \frac{\sum_{l} \eta_l S_l}{\sum_{l} \eta_l} \qquad (2)$$

and

$$UE = A\frac{\sum_{i} \alpha_i P_i}{\sum_{i} \alpha_i} + B\frac{\sum_{j} \beta_j R_j}{\sum_{j} \beta_j} + C\frac{\sum_{k} \gamma_k Ph_k}{\sum_{k} \gamma_k} \qquad (3)$$

Where:

- ζ controls the relative weight given to the quality of service parameters compared to the user experience parameters.
- A, B, C are empirically-determined weighing constants for the respective perception measures, rendering quality, and physiology measures.
- α_i β_j γ_k η_l are weighing factors which depend on the relative quality value of individual user experience parameters underneath perception measures, rendering quality, physiology measures, and quality of service measures, respectively.
- P_i R_j Ph_k S_l represent the quality values given to individual parameters of perception measures (P_i), rendering quality (R_j), physiology measures (Ph_k), and quality of service measures (S_l).

If the quality factors are restricted between 0 and 1, then the overall quality of experience will also have a value between 0 and 1 (i.e. 0 ≤ QoE ≥ 1). To achieve this condition, the constant coefficients A, B, and C in equation (2) should satisfy the constraint:

$$A + B + C = 1 \qquad (4)$$

5. Evaluation Case Studies

In this section, we try to experiment the proposed model with two haptic user interface (HUI) applications that we have developed at the DISCOVER lab of the University of Ottawa: the haptic learning system [10] and the haptic-enabled UML CASE tool [11]. The usability analysis is used to assess effectiveness of the proposed model by comparing the overall QoE computed using the mathematical model with that provided by the testing subjects.

5.1 Evaluation Metrics

The proposed model includes a comprehensive list of parameters that can be used for evaluating HUI applications. For the purpose of evaluation of the two particular applications that we have, we have selected related parameters that we think are most related. For example, since both applications were standalone applications, there was no way to incorporate collaboration measures or tele-presence in this analysis. Therefore, the following criteria were selected from the evaluation model:

- Ease of use (from the haptic perspective): Is it easy to use the haptic device?
- Rendering quality/haptics: Does the haptic device provide realistic force feedback?
- Modality choices: Is there a choice to turn off certain modalities / do various modalities provide a better experience?
- Side effects/fatigue: To what extend, if any, did the haptic device cause fatigue?
- User satisfaction: Give a grade, over 100, for the overall quality of the application?
- Haptic interface stability and transparency: To what extent do you think the haptic playback was realistic?
- Error rate: this is evaluated by measuring the performance of the user (such as the task completion time or task error rate).

5.2 Applications and Experimental Setup

5.2.1 Haptic Learning System

The haptic learning system is designed to facilitate learning of alphabetic handwriting of various languages by incorporating visual, auditory, and haptic feedback. The application is a graphical user interface that is divided functionally into four blocks: the alphabets keyboard, the review window, the workspace area, and the control panel (Figure 6). The alphabets keyboard contains all the characters of a particular language (the system supports in its current state five languages: Arabic, English, Chinese, Japanese, and French). The review window replays graphically the selected character whereas the workspace enables users to experience the handwriting and receive back the haptic and graphic feedback about the user writings. Finally, the control panel controls the playback mode (graphic and/or haptic and the guidance level such as no, partial, or full). [7]

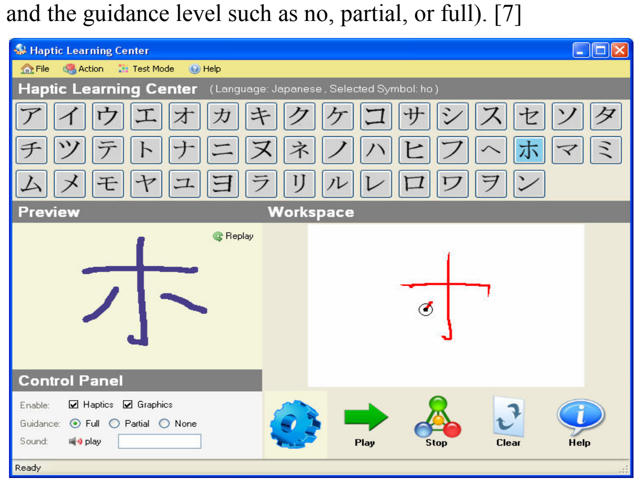

Figure 6. A snapshot of the haptic learning system

Fifteen test subjects were asked to practice using the haptic learning tool. The subjects were asked to practice the handwriting of three Japanese characters (ho, ki, and yo), three times each. Then they were asked to write the characters on a sheet of paper and the score was saved for each. Both the graphical appearance and the stroke sequence were considered to verify the correctness of the letters. Finally, the subjects were asked to complete the questionnaire.

5.2.2 Haptic-enabled UML CASE Tool

Unlike traditional UML CASE tool that rely on input/output devices such as the keyboard and the mouse, this tool uses a haptic device in order to provide better and more intuitive means for UML software developers. The haptic feedback includes a gravity simulation for the classes, an elastic force between classes, and a collision force when two classes collide. The tool has three basic components: a drawing area, a palette, and a tool bar (Figure 7). The palette contains the basic modeling elements to create the diagram, which is then displayed in the drawing area. The tool bar provides filing functionalities to the user such as save, open, new, and print. [8]

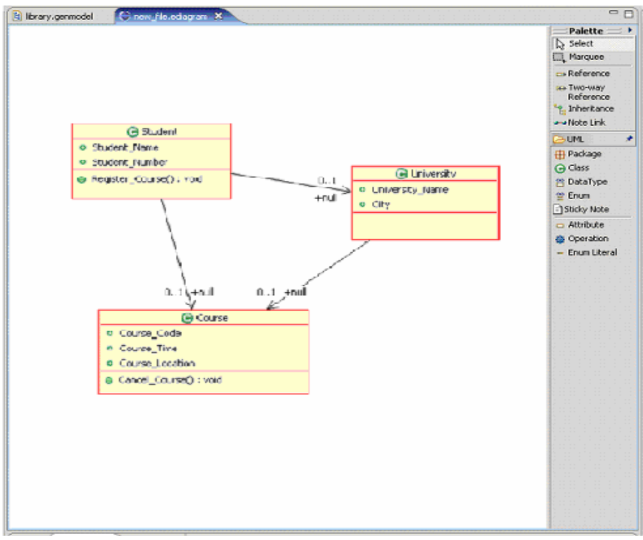

Figure 7. Haptic-enabled UML CASE tool

Fifteen test subjects were asked to complete a simple UML class diagram using the haptic device and then to complete a questionnaire. The results of this test were used to assess whether the criteria of the evaluation model correlated with the overall user experience stated explicitly by the users in the questionnaire.

5.3 Results

The questions provided in the questionnaire were meant to collect information about the evaluation criteria selected for the tests. Each question was given a value between 0 and 5 ("Yes or No" questions were rated as 0 for "No" and 5 for "Yes"). An average was then calculated for each question. To find the overall value of each criterion, the average of the questions relating to that criterion was calculated. The results for each of the evaluation criteria are summarized in the Table 2.

Table 3 describes the weighting factors used for each parameter. These variables require a significant effort to optimize their values to best represent the importance of each parameter. Given the weighting factors and the average quality values for each parameter, we have computed the overall quality of experience for the two applications. At the same time, we asked the users to provide a subjective evaluation (over hundred) for the quality of experience of the application. Finally we compared the two results in Table 4. Notice that the quality of experience computed by the proposed model is pretty close to that given by the users. This implies that the model is able to measure the quality of experience of the users.

Table 2. Averages for evaluation criteria

Criterion		Haptic learning system (/5)	UML CASE Tool (/5)
Perceptual measures	Ease of use	4.60	3.33
	Modality choices	5	2.88
	Side effects/fatigue	4.7	2.93
	User satisfaction	5	3.82
Rendering quality	Device stability and transparency	3.9	3.33
	Error rate	4.4	3.41
	Haptic rendering quality	4.40	4.22

Table 3. Weighting factors used for mathematical model

Criteria		Weighting factor	
		Haptic learning system	UML CASE Tool
Perceptual measures	Ease of use	6	6
	Modality choices	2	2
	Side effects/fatigue	3	3
	User satisfaction	5	5
Rendering quality	Device stability and transparency	5	5
	Error rate	4	4
	Haptic rendering	5	5

Table 4. A comparison between the Quality of Experience calculated using a model versus that using usability analysis

Criteria	Quality of Experience	
	Using mathematical Model	Using usability analysis
Haptic learning system	91.67	89
UML CASE Tool	70.01333	73

6. Conclusion

This paper proposed a taxonomy and evaluation model for haptic user interface applications and a mathematical model to incorporate the quality parameters in order to measure the overall quality of experience of HUI application. However, this evaluation model, as well as the mathematical model, were a starting point for haptic-based environments evaluation, and as such are basic models which can be expanded upon.

Haptic-based GUIs are a fairly new application domain, and more research needs to be done in this area to create a model that precisely reflects the quality of experience of a HUI application. Furthermore, the model has several constant parameters that need calibration. Therefore, one of our future avenues is to experiment with large number of applications from different domains to come up with the best values of these parameters that best reflect the user experience.

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