A Fuzzy Logic System for Evaluating Quality of Experience of Haptic-based Applications

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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 (QoE) when haptic modality is incorporated in a virtual user interface has received limited attention from the research community. In this paper, we propose a taxonomy for measuring the quality of experience of Virtual Reality (VR) applications. Furthermore, the taxonomy is modeled using a Fuzzy Logic Inference System (FIS) to quantitatively measure the QoE of a haptic virtual environment. Finally, the proposed model is tested using the Mamdani system. The simulation and usability analysis demonstrated that the proposed model reflects the user estimation for the applications more accurately and thus is capable of measuring the overall QoE of a haptic application.

Keywords: haptics, quality of experience, fuzzy logic

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. The advantages of haptics audio and video environments include more realism, more excitement, and better manipulation of objects. Thus, it is not far away to see haptic e-commerce applications over the Internet [1]. Nonetheless there is a lack of measurement of these advantages objectively through a concrete evaluation model. Quality of Experience (QoE) is an evolving research topic concerned in evaluating virtual environments. The measured QoE is an indicator of the level of perception and 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 reflects the 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 users can not differentiate it 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 have hindered the progress in that field [2].

In this paper, we propose a taxonomy for QoE evaluation metrics associated with haptic-based virtual environments. This taxonomy includes the related parameters that are necessary to assess and test the advantage/disadvantages of a haptics application. We also propose a fuzzy logic inference system to model the QoE of an application. The purpose of the fuzzy logic system is to quantify and measure the QoE parameters objectively instead of having subjective evaluation.

The rest of the paper is organized as follows. First we review the related work in the field of QoE for virtual reality applications. Next, we present our taxonomy for QoE parameters including the complete charts and our rationale behind that taxonomy. Then our fuzzy inference system that is based on the taxonomy is proposed. Analysis of our system and the results obtained are analyzed afterwards. Finally, we conclude this paper and state the future work.

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 user involvement. It has been used as a complementary approach to conducting a statistical survey. Some of the parameters that are included in the 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 VR 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. Measuring those symptoms directly is more effective than a questionnaire due to three limitations [6]:

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 Model

In this section we briefly describe the QoE model and the taxonomy we used to incorporate the different parameters. A detailed description of the taxonomy and a preliminary evaluation with mathematical modeling can be found in [7]. This higher level organization, shown in Figure 1, reflect an apparent taxonomy for VR applications evaluation, 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 portion.

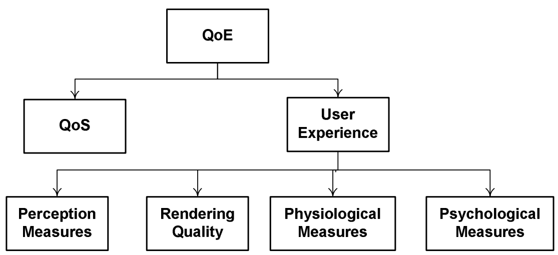


Figure 1. Higher level organization of QoE model

3.1 Quality of Service Parameters

QoS parameters insure the smooth flow of the application. 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 and media synchronization which include the synchronization of the three media streams; graphics, audio and haptics.

Table 1. Quality of Service Parameters

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

3.2 User Experience

3.2.1 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. Furthermore, 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.

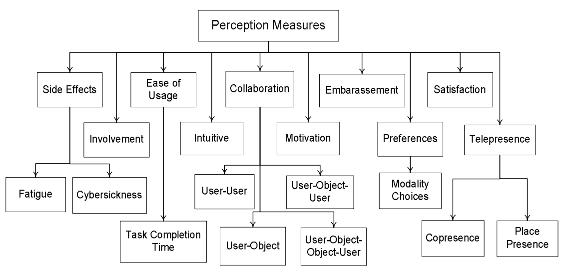


Figure 2. Perception Measures Parameters

3.2.2 Rendering Quality

The Rendering Quality measures the quality of the three major modalities, namely: graphics, audio, and haptics. Each modality is evaluated separately first and eventually blended and mixed modalities are evaluated. As seen in Figure 3, there is an emphasis on haptics modality since it has very stringent requirements in terms of feedback loops which might affect the stability and transparency of the application.

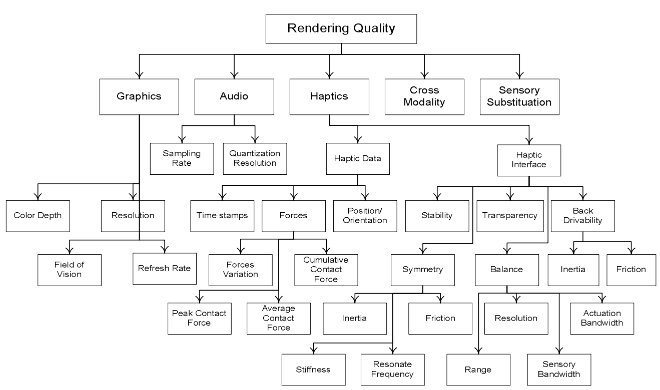


Figure 3. Rendering Quality Parameters

3.2.3 Physiological Measures

Physiological measures are biological parameters that are measured directly from the user's body while they are using the application. These parameters determine directly factors such as cybersickness, stress, and brain activity (Figure 4) [2].

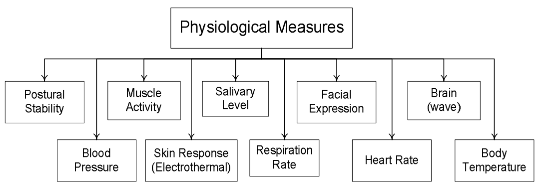


Figure 4. Physiological Measures Parameters

3.2.3 Psychological Measures

Unlike the physiological measures, psychological measures reflect the status of the user through observation but not through direct measurements. Psychological Measures are displayed in Figure 5.

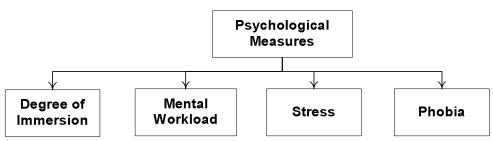


Figure 5. Psychological Measures Parameters

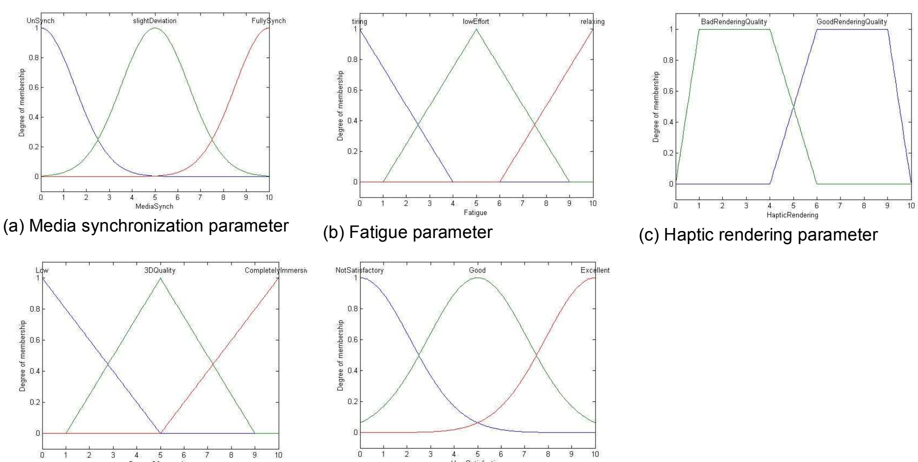
4 Fuzzy Inference System (FIS)

It has been observed that, aside from Quality of Service and Physiological Measures, most QoE parameters are subjective and are fuzzy in nature. For instance there is no crisp answer to whether the user is under stress or whether the application is easy to use. Therefore, a fuzzy logic system is needed to map the fuzzy logic inputs to a crisp fuzzy output, which is in our case a Quality of Experience value. The system would vary in the number of inputs provided along with their membership functions, depending on the type of application we are trying to evaluate. As a proof of concept, we picked out five parameters that are relevant to a particular application, named Balance Ball game [8], where the user is immersed in a 3D application. The five parameters act as the input to the FIS as described in the following subsections.

4.1 Building the Fuzzy Inference System (Input/Output Design)

We made an effort to diversify the input to the fuzzy logic system, by selecting parameters from several categories. Each input has a different type of membership function, depending on the property of the parameter. The five membership functions are displayed in Figure 6 and were selected according to the following reasoning:

A) Media Synchronization (QoS parameter) - should have Gaussian waveform with high decay rate since miss-synchronization of different media might cause a drastic loss of the perception of both media.
B) Fatigue (Quality of perception) - This can be a simple triangular membership function since fatigue is linearly distributed.
C) Haptic rendering (Rendering Quality) - this can be a trapezoidal function due to the fact that the haptic rendering quality remains the same until we reach a threshold (that is usually referred to as the JND - Just Noticed Difference) after which the quality starts decaying.
D) Degree of immersion (Psychological measures) - Linear triangular membership function as immersion is also linearly distributed based on the user.
E) User Satisfaction (Quality of perception) - This is again a Gaussian membership function because of the normal distribution of human satisfaction measures.



(a) Media synchronization parameter (b) Fatigue parameter (c) Haptic rendering parameter
(d) Degree of immersion parameter (e) User Satisfaction parameter

Figure 6. The five input membership functions

We have implemented the model using the well known and established Mamdani inference system [9], shown in Figure 7. The Mamdani system uses defuzzified output which is based on membership functions as displayed in Figure 8. The QoE output function is divided into five membership functions, in increasing order they are: InTolerable, UnAcceptable, Average, Excellent, and Perfect.

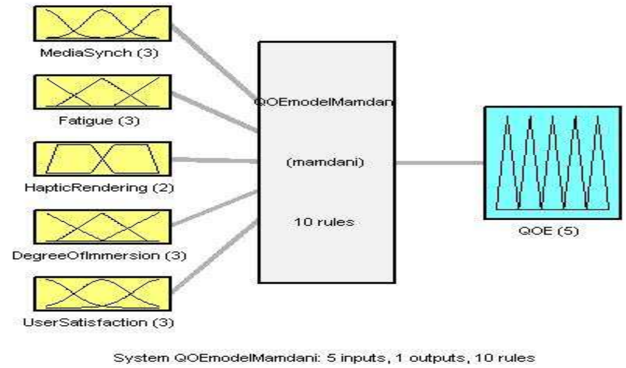


Figure 7. Mamdani fuzzy inference system

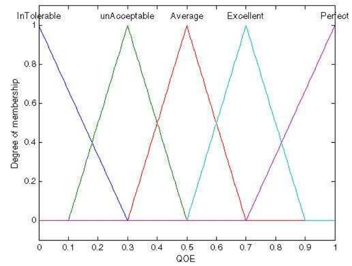


Figure 8. Output membership functions for Mamdani *FIS*

4.2 Rule Selection

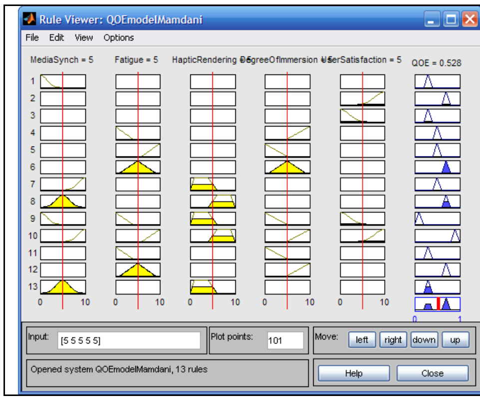
There are certain rules that should take place no matter what are the other parameters' values because they are critical for the overall perception of the application. On the other hand, parameters such as fatigue and immersion have opposing effect, to the quality of the application. These relations can be formulated and added to the system as rules (see Table 2). Additionally, media synchronization and haptic rendering also have a special relation. Haptic rendering quality remedies the effect of bad media synchronization (if unsynchronized however QoE is unacceptable based on the previous rule). In the same way, bad haptic rendering quality can be remedied by excellent media synchronization. A selected set of rules that have been used within the Mamdani system are displayed in Table 2.

Table 2. Rule selection

Media Synchronization	*If media synchronization is unsynch then QoE is unAcceptable*
User Satisfaction	*If user satisfaction is NotSatisfactory then QoE is unAcceptable* *If user satisfaction is Excellent then QoE is Excellent*
Compound	*If Fatigue is tiring and Immersion is Complete then QoE is Average* *If Fatigue is Relaxing and Immersion is Low then QoE is Average* *If Fatigue is lowEffort and Immersion is 3DQuality then QoE is Excellent*
General	*If all inputs are minimum (bad) then QoE is InTolerable* *If all inputs are maximum (at best) then QoE is Perfect*

4.3 Testing the Fuzzy Logic System

To test the system we ran both visual tests and command based testing in MATLAB. The visual testing involved running the MATLAB fuzzy logic toolbox, called ‘rule viewer’. The rule viewer gives a visual aid on which rules are selected and activated and their effect on the output. The input can be given by dragging the red line over the input or in the text box provided at the bottom (Figure 9(a)). The command based testing eased the testing process since we had the option to run script like the one shown in Figure 9(b). The script fixes all inputs to nine except for the first input (media synchronization) that is incremented from one to ten. Subsequently, MATLAB will display the results of the ten QoE values corresponding to each media synchronization value.




```
>> mamdani = readfis('QOEmodelMamdani.fis')

mamdani =
  name: 'QOEmodelMamdani'
              type: 'mamdani'
         andMethod: 'min'
          orMethod: 'max'
      defuzzMethod: 'centroid'
         impMethod: 'min'
         aggMethod: 'max'
             input: [1x5 struct]
            output: [1x1 struct]
              rule: [1x13 struct]

    >> for j=1:10,
    qoe = evalfis ([j 9 9 9 9], mamdani)
end
```

Figure 9. (a) Rule viewer of MATLAB’s fuzzy logic toolbox, (b) An Excerpt of Matlab script

4.4 Usability Analysis and Comparison

For the Balance ball experiment, we used two Pentium 4 PCs with 1 Gb RAM. The two haptic devices were the Phantom Omni and the Phantom Desktop, developed and marketed by SensAble Technologies, Inc. [10]. The experiment was conducted on an Ethernet Local Area Network with ALPHAN [8] over UDP as the transport protocol. Network disturbances such as delay and jitter were simulated using a software tool we developed for this experiment. In order to make use of the jitter smoothing algorithm, the clocks of both workstations were synchronized using Network Time Protocol (NTP) server. Both workstations maintained a connection with the NTP server with clock synchronization precision falling within one millisecond.

To evaluate the system from a user perspective, we designed a questionnaire for users who experienced the Balance Ball Game application. The users were asked to provide their estimation for the selected five parameters (shown in Table 3) and the overall QoE. We then input the user feedback values to the fuzzy logic system and generated the corresponding QoE. The comparison between the FIS results and the usability analysis per each user is presented in Table 4.

Table 3. Usability analysis results

	Input (%)				
Users	Media Synchronization	Fatigue	Rendering	Deg. of Immersion	User Satisfaction
U1	80	40	80	100	100
U2	80	20	80	100	100
U3	80	40	80	100	80
U4	100	20	80	80	100
U5	100	20	60	80	80
U6	100	20	100	60	60
U7	80	80	100	80	40
U8	40	80	40	80	60
U9	80	60	80	80	100
U10	80	20	100	80	100

Table 4. Comparison between FIS and usability results

Users		*U1*	*U2*	*U3*	*U4*	*U5*	*U6*	*U7*	*U8*	*U9*	*U10*
Output	*Usability*	*85*	*90*	*90*	*95*	*90*	*90*	*92*	*80*	*90*	*95*
	FIS	*70*	*75.3*	*69.9*	*76.2*	*75.8*	*66.9*	*51.7*	*44.2*	*70*	*70*

The user perceived QoE in some cases does not reflect the value of inputs. This indicates that users sometimes, especially if they are new to haptic devices, get so excited and pleased by the virtual application that they tend to complement the application rather than accurately estimating their perception and level of experience. The FIS output on the other hand eliminates these issues. For instance with U8, the input values were relatively low in magnitude, however the perceived QoE was unexpectedly high. The FIS output for U8 is more accurate and actually corresponds to the value of the inputs.

Another point to consider is the fact that some parameters are important to acquire the benefits of the full experience of the application. Users can be distracted by so many features that they may not regard certain features when evaluating their experience. With U5 the haptic rendering was slightly above average while the perceived QoE was 90%. Haptic rendering is an important factor to take into consideration and the QoE output of the fuzzy logic system account for this.

5 Conclusion and Future work

This paper presents a taxonomy for evaluating the quality of experience of a haptic virtual environment and proposes a fuzzy logic system to model the taxonomy. The proposed model is simulated and tested using a well known FIS: the Mamdani system. Furthermore, a usability analysis has been conducted to test whether the proposed model is capable of reflecting the user estimation for the QoE of the application. The obtained results were satisfactory.

As a future work, we are planning to extend the proposed taxonomy; particularly for the physiological and psychological measures. Furthermore, the taxonomy and proposed FIS will be examined using haptic environments from a wide spectrum of applications. This leads to better understanding of which parameters contribute the best to the quality of experience for a particular application. Finally we will remodel our system using another known FIS: the Sugeno system [11], and compare it with our current findings.

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