Deducing User's Fatigue from Haptic Data

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ABSTRACT

Undesired physical fatigue reduces the overall Quality of Experience (QoE) of virtual reality haptics applications. Detecting fatigue is the first step in rectifying this problem. Fatigue in usability analysis is usually detected through conducting questionnaires and observations. This paper introduces an objective indirect discovery of user's fatigue through analyzing data of a haptic writing application. Our results show that if users are feeling tired their kinetic energy would decrease. We can compute this kinetic energy from the velocity of the arm movement during the usage of the haptic device.

Categories and Subject Descriptors

H.1.2 [**Models and Principles**]: User/Machine Systems – *Human factors.*

General Terms

Performance, Experimentation, Human Factors

Keywords

Fatigue, Physical energy, Haptics, Quality of Experience

1. INTRODUCTION

With new interactive interfaces emerging such as haptic interfaces [1, 2], applications are becoming more user-centric. It is therefore necessary to assess the overall satisfaction of the user of such interfaces. One factor that we propose to evaluate is user's fatigue, which is classified into mental fatigue and physical fatigue. Physical fatigue is of importance when it comes to haptic manipulation as the arm is moving continuously. Physical fatigue is defined as the inability to work certain muscles according to the capability of the individual [3]. Physical fatigue is associated with lack of energy which indicates that the ability of individuals to continue the task diminishes with time as they continue their activity without rest. On the other hand, mental fatigue is not correlated with muscle movement and thus it is of less concern to haptic manipulation since it is application dependent. In this paper, we will be referring to physical fatigue as fatigue by itself.

Fatigue could be an undesired byproduct of haptic-based applications. In some cases, however, fatigue can increase the quality of the application if the desired goal is, for example, to increase the endurance of the user in virtual exercise training. In both cases, fatigue assessment is important and can lead to better evaluation of the Quality of Experience (QoE) of haptic-audio-visual applications. In [4], we have shown the role of fatigue in shaping the QoE evaluation of a haptic-based application. Fatigue was determined based on a questionnaire administered to users of the system as well as observations done during usage of the haptic device. Reported results of the questionnaire were transformed into percentage quantity for each user.

The subjective analysis of fatigue through questionnaire may fit into certain contexts such as [4]. However, in certain cases we might need to compute fatigue objectively without a questionnaire and without involving the user at all. Subjective evaluation, though useful in many scenarios, has been criticized by directly engaging the user in the evaluation leading the results to be slightly biased according to users' interpretation [5]. An indirect measurement is harder to define but will get the intended results with the advantage of the user being unconscious of the whole procedure and what is being measured.

In this paper, we use indirect measurement to objectively detect users' fatigue when working with a haptic-enabled application. The data collected during the interaction with the application are analyzed to see if there are patterns that would indicate signs of fatigue. These patterns can then be used by the designers of the application to control the flow of movement according to the context of the application.

The rest of the paper is organized as follows. In Section 2, we review the related work concerning fatigue and haptic virtual environments. Section 3 describes the experimental setup and the data that we have collected. We introduce our assumptions and calculation methods in Section 4. In Section 5, we analyze the data and the results we obtained. Finally, we conclude the paper and state the future work in Section 6.

2. RELATED WORK

Fatigue traditionally has been assessed using a questionnaire. For instance, [6, 7] use questionnaire to detect the fatigue among users during different situations and lack of sleep scenarios.

In [8], the authors analyze the level of familiarization and fatigue for different contact states using the CyberGlove and cylindrical objects. The analysis is based on the tasks that will cause fatigue such as moving from light to heavy grasps. In [9], the authors measure the effect of an armrest when maneuvering master control devices. The assumption is that the arm rest will reduce muscle fatigue by reducing the gripping force necessary to maneuver the device.

In a different direction, Kahol et al. [10] measure the fatigue of surgical residents by assessing their psychomotor and cognitive skill evaluation using a virtual reality simulator with haptic feedback. Fatigue via surgical skills was assessed by task completion time, hand-and-tool-movement smoothness, and cognitive errors.

Reference [11] provides a framework for modeling a digital human in virtual reality environment. The virtual human has a set of parameters that would describe the motion but unique in this paper is the modeling of fatigue and incorporating it in the framework. Joint fatigue is evaluated by the decrease of strength in the joints. The virtual framework is tested using a virtual human undergoing a hole-drilling task.

3. HAPTIC SIGNATURE APPLICATION

In [12] we have developed a haptic application that allows users to hapticaly write on a virtual background. In our particular case, the users were required to hapticaly sign the virtual application. The data acquired was used to identify users based on haptic features collected. In this paper, we use the same application running in three dimensions on different hardware to infer users' fatigue using similar sets of data collected.

3.1 Application Description

The haptic writing environment provides a virtual environment where users can perform various writing tasks including writing their own signature on a virtual plate. As can be seen in Figure 1, the users manipulate the haptic device as a pen and its 3-dimensional position is mapped to a cursor in the virtual environment. When the cursor collides against a white rectangular virtual plate, the users can feel the repulsive force based on the penalty-method and blue dots are drawn on the collision position. A Phantom Desktop haptic device was the haptic device of choice for this application since it has six degrees of freedom related to positional and rotational movement and three degrees of freedom related to force feedback. Most importantly, it can measure 3-dimensional position and orientation of the end-effector. The hardware setup displayed in Figure 1 is manufactured by Reachin Technologies. It allows users to work in a three dimensional environment adding more realism to the virtual reality application.

Figure 1. Haptic signature application. This figure shows a user signing his name on virtual background using a haptic device.

3.2 Experimental Setup

Fifteen male users of different ages (25-35) have volunteered to participate in the experiment. The level of haptic experience varied between users. We requested every user to provide sixty handwritten signatures using our system. We dipd not start the experiment until the user felt comfortable with the environment and after virtually signing at least once without any complications. For users who have experience with haptic devices, we started capturing their signatures from the second trial. Each user performed 60 recorded trials. Users were asked to fill out a short questionnaire after the 30th trial as well as the 60th trial. The questions reflect the users' mental state during the middle and end of the experiment regarding their fatigue level. The questionnaire provides the subjective results required to reinforce and validate the fatigue inference we conducted on the data collected.

3.3 Data Collection

Many attributes have been recorded during the performance of the trials. When a user writes his/her signature on a virtual plate, the 3-dimensional position (p), force applied (f), velocity (v), and angular rotation (a) of the virtual pen-tip were measured and recorded in a csv file at each timestamp (t). A simple element that represents a state in our system can be described as the vector $s = \{p_x, p_y, p_z, f_x, f_y, f_z, v_x, v_y, v_z, a_x, a_y, a_z, t\}$ where subscript x, y, and z represent spatial dimensions. Each trial consists of thousands of *s* elements.

4. Energy Calculation

Users' constant motion can lead to users being tired after certain amount of time. The more time they spend utilizing their muscle forces the more tired they are going to get. Fatigue has been linked to the lack of energy in users [3]. Our assumption here states that if the user manipulating the haptic device gets tired by applying force over a certain period of time then his/her energy level would decrease in magnitude.

Energy is divided into potential energy and kinetic energy [13]. Since the arm movement that manipulates the haptic device involves position displacement, we focused on examining the kinetic energy and its relation with fatigue. The following formula defines the kinetic energy where m is the mass and v is the velocity magnitude,

$$E_k = ½ mv^2 \qquad (1)$$

For a given user, the mass of the haptic device and the user's arm is constant. Looking at equation 1, if we want to compute the difference in energy for the same user, then, the only variable that is changing is the velocity magnitude since the mass is constant. Therefore the difference in energy at any given time can be formulated as follows

$$E_{k1} - E_{k2} = ½ mv_1^2 - ½ mv_2^2 = ½ m (v_1^2 - v_2^2) \qquad (2)$$

Consequently, the magnitude of the velocity is the deciding factor to examine the change in kinetic energy for a given user at any point in time. For a user x, the task performed is the repetitive hand signature task for 60 trials. For that specific user, the signature is constant and hence the task is constant relative to the user. The force F applied by the user is divided into fx, fy, and fz according to the Euclidean space. Each force is associated with a Euclidean space displacement given by vector D which can also be divided into dx, dy, and dz. From displacement over time the velocity in each direction can be computed and the velocity magnitude can then be calculated.

Since the results constituted hundreds of data vectors, for each trial, sampled at fractions of a second, we averaged each 30 together to get the velocity over a bigger time frame. Our algorithm for computation is shown in Figure 2.

```
for each user
 for each trial
  for each sample greater than 1
    calculate deltaX , add it to displX
    calculate deltaY, add it to displY
    calculate deltaZ, add it to displZ
    if (sample number reaches 30)
            velX = displX/(deltaTime for the 30 samples)
            velY = displY/(deltaTime for the 30 samples)
            velZ = displZ/(deltaTime for the 30 samples)
            Ei = velX ^ 2 + velY ^2 + velZ^2
            Store Ei, reset values
for each user
      for each trial greater than 30
            Ediff = Ei at 30 – Ei at current trial
            Sum = Sum + Ediff
      store sum
for each user plot sum vs trial (start from trial 31)
```

Figure 2. Algorithm for computation of energy.

Our goal is to compute the sum of the energy differences between different trials and to determine if the energy is decreasing or increasing with successive trials.

From the algorithm above, it can be noticed that we started our base trial at trial 30 not at trial 1. As practice might affect the velocity of the user, we wanted to distinguish between learning time and actual velocity changes due to decrease in energy. To monitor the effect of learning we need to examine the task completion time (TCT) of the users of the application.

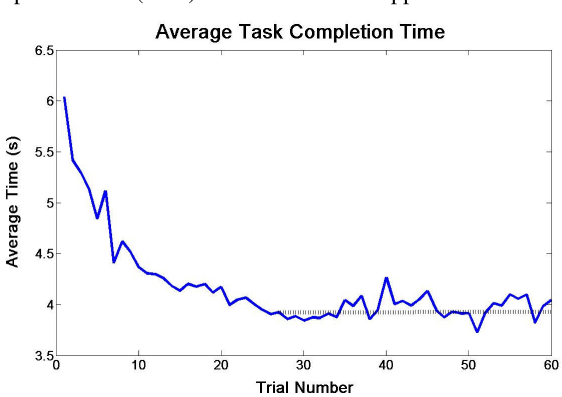

Figure 3. TCT average value per trial.

Figure 3 shows that the TCT per trial averaged for all users keeps decreasing until trial 27 where the TCT stabilizes around 4 seconds. The TCT fluctuates above and below 4 seconds for subsequent trials but it does not increase or decrease strongly as it does with the first 20 trials.

The decrease of the average TCT per trial over the first 27 trials indicates that users are in learning phase and with repeated trials they are getting used to the hardware and the exercise. When the average TCT stabilizes around trial 27, the users have passed the learning phase and are now comfortable with using the hardware and with signing the virtual cheque. After that trial, we can analyze the energy of the users with the learning effect at a minimum. We chose trial 30 as the base trial to be certain that learning process is over.

5. RESULTS AND DATA ANALYSIS

5.1 Questionnaire Results

The results of the questionnaire given to users right after trial 30 and trial 60 (last trial for each user) are displayed in Figure 4.

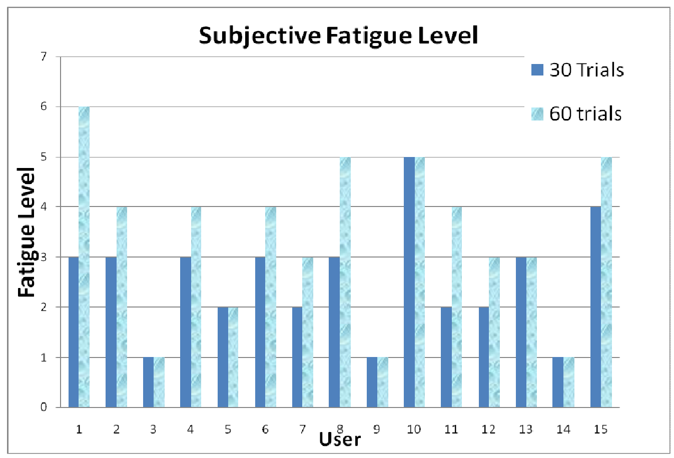

Figure 4. Fatigue level questionnaire results.

Figure 4 displays the result of the Likert questionnaire administered to the users which investigate the level of fatigue they are experiencing during their haptic usage. The Likert scale ranged from one to seven (seven donating high fatigue).

Based on the results, we can notice that most users did feel more tired at the end of the experiment when compared to the middle of the experiment. Other users indicated that their fatigue level remained the same thourgout the trials 30 to 60.

5.2 Energy Difference

As mentioned in Section 4, we took the energy difference as a sum of energy differences between two trials at various times during the experiment. We took trial 30 as the base trial and compared the differences of later trials with the energy at trial 30.

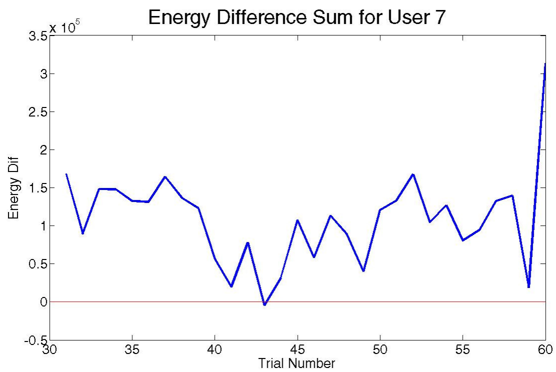

Figure 5. Energy difference between trials 31 to 60 and trial 30 for user 7.

Figure 5 shows the result of one user of the application. The graph specifies that the user energy level in most cases is above zero. This indicates that for user 7, the sum of energy of trial 30 was greater than the sum of energy of most trials afterwards till the end of the experiment. Relating this result to the results depicted in Figure 4, we observe that user 7 indeed indicated that he is experiencing more fatigue at the end of the experiment rather than in the middle of the experiment.

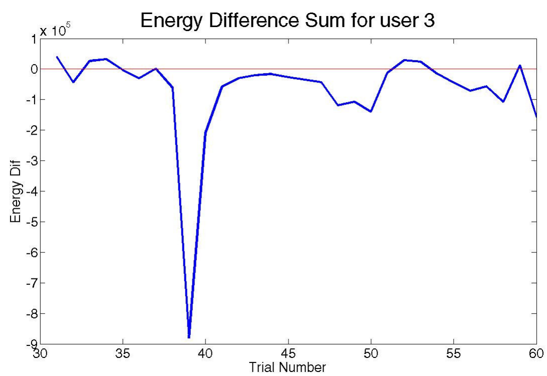

Figure 6. Energy difference between trials 31 to 60 and trial 30 for user 3.

Figure 6 shows the result of another user of the application who reported no difference in his perceived fatigue level (see Figure 4). User 3 energy differences between trial 30 and subsequent trials revolve around zero and dip into the negative in some cases. This means that his kinetic energy did not decrease overall and in some cases increased, which explains why he did not feel more tired by the end of the experiment.

Based on that analysis above we get 73.3% of the users who comply with that assumption. Their kinetic energy difference was in the positive compared to the base trial when they reported feeling fatigue by the end of the experiment, or their kinetic energy difference compared to the base trial was in the negative when they reported no change in fatigue between the middle and the end of the experiment.

6. CONCLUSION

This paper presented a way of detecting fatigue for haptic-based applications. Fatigue was detected by calculating the variation in user's energy in a time interval. The magnitude of the variation is out of scope of this paper but should be addressed in the future. Undesired fatigue reduction can increase the QoE of a given application. Ways to reduce fatigue resulting from haptic devices is an open area of research and should be considered for future work. One suggestion is to use armrests but that is not always feasible depending on the application. Another suggestion is to use rest intermissions during usage of the haptic device but again that is application dependent.

7. REFERENCES

[1] El Saddik, A. 2007. The potential of haptics technologies. *IEEE Instrumentation and Measurement Magazine*. 10, 1 (Feb. 2007), 10-17.

[2] Eid, M., Orozco, M., and El Saddik, A. 2007. A guided tour in haptic audio visual environment and applications. *J. Advanced Media and Communication.* 1, 3, (2007), 265-297.

[3] Lou, J.S. et al. 2001.Exacerbated physical fatigue and mental fatigue in Parkinson's disease. *Movement Disorders.* 16, 2 (2001), 190-196.

[4] Hamam, A., Eid, M., El Saddik, A., and Georganas, N.D. 2008. A fuzzy logic system for evaluating quality of experience of haptic-based applications. In *Proceedings of EuroHaptics 2008*, 129-138.

[5] Whalen, T. E., Noel, S., and Stewart, J. 2003. Measuring the human side of virtual reality. In *International Symposium on Virtual Environments, Human Interfaces, and Measurement Systems*. (Switzerland, July 27-29, 2003).

[6] Lee, K.A., Hicks, G., and Nino-Murcia, G. 1991. Validity and reliability of a scale to assess fatigue. *Psychiatry Research*. 36, 3 (1991), 291-298.

[7] Beurskens, A. et al. 2000. Fatigue among working people: validity of a questionnaire measure. *J. British Medical*. 57, 5 (2000), 353-357.

[8] Kondo, M., Ueda, J., Matsumoto, Y., and Ogasawara, T. 2005. Evaluation of manipulative familiarization and fatigue based on contact state transition. In *Proceedings Eurohaptics 2005,* 107-112.

[9] Ito, S. and Yokokohji, Y. 2009. Manoeuvrability of master control devices considering the musculo-skeletal model of an operator. In *Proceedings of World Haptics 2009,* 57-62.

[10] Kahol, K.et al. 2008. Effect of fatigue on psychomotor and cognitive skills. *American Journal of Surgery*. 195, 2, (2008), 195-204.

[11] Ma, L., Chablat, D., Bennis, F., Zhang, W., Hu, B., and Guillaume, F. 2010. Fatigue evaluation in maintenance and assembly operations by digital human simulation in virtual environment. *Virtual Reality* (March 2010), 1-14.

[12] Alsulaiman, F.A., Cha, J., and El Saddik, A. 2008. User identification based on handwritten signatures with haptic information. In *Proceeding of EuroHaptics 2008*, 114-121.

[13] The physics classroom http://www.physicsclassroom.com/Class/energy/U5l1c.cfm last access May 05, 2010.