Analyzing User Behavior within a Haptic System

Steve Johnson[1], Yueqing Li[1], Chang Soo Nam[1], and Takehiko Yamaguchi[2]

[1] University of Arkansas, Fayetteville, AR, United States
{sajohns,yxl002,cnam}@uark.edu
[2] Laboratoire d'Ingénierie des Systèmes Automatisés (LISA)
Université d'Angers, 62 Avenue ND du Lac – 49000 Angers, France
{takehiko.yamaguchi}@univ-angers.fr

Abstract. Haptic technology has the potential to enhance education, especially for those with severe visual impairments (those that are blind or who have low vision), by presenting abstract concepts through the sense of touch. Despite the advances in haptic research, little research has been conducted in the area of haptic user behavior toward the establishment of haptic interface development and design conventions. To advance haptic research closer to this goal, this study examines haptic user behavior data collected from 9 participants utilizing a haptic learning system, the Heat Temperature Module. ANOVA results showed that differences in the amount of haptic feedback result in significant differences in user behavior, indicating that higher levels of haptic friction feedback result in higher user interaction proportions of data. Results also suggested that minimal thresholds of friction haptic feedback can be established for a desired level of minimum user interaction data proportions, however; more research is needed to establish such thresholds.

Keywords: Haptic User Interface, Thermal Device, User Behavior, Inclusive Design.

1 Introduction

Haptic technology enables users with the ability to touch, feel, and interact with virtual objects in a computer simulated virtual environment as if they were real, physical objects. Haptic devices, coupled with sophisticated software applications, allow the user to interact with haptically rendered objects exhibiting a variety of surface textures and hardness in both two and three dimensions [2]. Haptic systems consider the unique physiological and psychological attributes related to the sense of touch and utilize haptic feedback to render haptic sensations [12]. Such haptic feedback is achieved through the haptic device via tactile, force, and torque feedback [6]. Haptic feedback tools such as gravity wells, indents, dimples, ridges, friction, and dampeners have emerged and are generally accepted among the haptic community with the specific purpose of providing users with anticipation, follow-through, indication, and guidance [14].

Haptic technology has the potential to enhance education, especially for those with severe visual impairments (those that are blind or who have low vision), by presenting

J.A. Jacko (Ed.): Human-Computer Interaction, Part II, HCII 2011, LNCS 6762, pp. 62–70, 2011.

abstract concepts through the sense of touch. As an assistive learning tool, haptic technology has proven to be effective - enriching and improving students' learning and problem solving ability by evoking haptic stimuli and sensorial feedback [3; 5; 11; 23], combining audio and haptic perceptions [7; 13; 25], and supporting tangible investigation and experimentation with concrete objects [10; 16; 18]. Likewise, the implementation of haptic force feedback has been shown to influence task performance and sense of copresence [1; 8; 21]. Finally, the natural pairing of haptic technology with the prevalence of virtual education research provides further building blocks towards combining learning with leisure [19].

Despite the advances in haptic research, technology, human sensing and control [4; 9], and haptic behavior [20; 22; 24], little research has been conducted in the area of haptic user behavior toward the establishment of haptic interface development and design conventions [5; 6]. This lack of research can be largely attributed to the cost, multi-domain knowledge, time, and effort associated with the design and development of haptic systems [15]. By proposing an acceptable method of analyzing haptic user behavior, it may be possible to establish proper methods in which to evaluate haptic technology, haptic methods, and haptic interface design and development. The overall goal of such a methodology is in maximizing ease of use in the domains of haptic interaction and haptic user interface design for both sighted and visually impaired users. To advance haptic research closer to this goal, this study examines haptic user behavior within the Heat Temperature Module, a haptically enhanced science learning system developed by the HCI research team at the University of Arkansas.

2 Heat Temperature Module

The Heat Temperature Module (HTM) is a science learning haptic application developed at the HCI lab at the University of Arkansas under the supervision of Dr. Chang S. Nam. HTM supports Viscosity Mode, Structure Mode, and Speed Mode. These aptly named modes allows users to haptically explore the Viscosity, Molecular Structure, and Molecular Speed of substances in cold, warm, and hot temperatures. Currently HTM includes the substances CO2, CS2, BF3, SO3, H2O, NO2, NH3, CH4, and PCL3. HTM supports the Novint Falcon Haptic Device as well as a custom Thermal Device developed by the HCI research team at the University of Arkansas (Fig. 1).

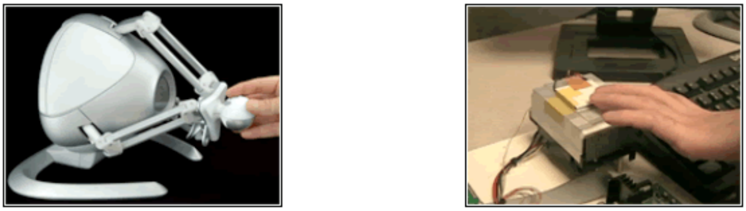

Fig. 1. Novint Falcon (left) and HCI Thermal Device (right)

The haptic device and thermal device are used in tandem to allow users to haptically feel an interactive object with one hand, while feeling the corresponding temperature of the object with the other hand. The Novint Falcon is a 2 DOF haptic device capable of rendering haptic forces just over 2 lbs (Novint Falcon, 2010). The HCI Thermal Device is an electronic device that consists of a touchable surface that is capable of rendering controlled temperatures between 0 and 40 degrees Celsius with a standard deviation of 1-2 degrees Celsius.

2.1 Viscosity Mode

Only HTM's Viscosity Mode is considered in this research. This mode contains three different 2D interfaces corresponding to the viscosity of a substance, in a liquid state, at hot (low viscosity), warm (medium viscosity), and cold (high viscosity) temperatures (Fig. 2).

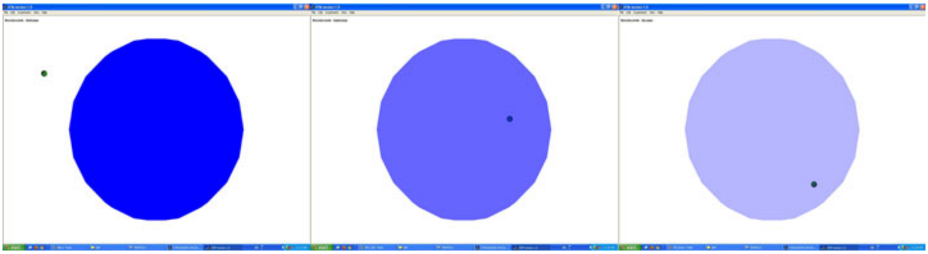

Fig. 2. HTM Viscosity Mode Cold (left), Warm (mid) and Hot (right) interfaces

Viscosity describes how easily a liquid pours or drains through a hole. Each interface contains a single substance, represented by a large two dimensional sphere, centered within a haptic boundary. The sphere haptically exhibits high, medium, and low friction to represent cold, warm, and hot temperature, respectively. Visually, the transparency of the substance changes at each temperature.

2.1 HTM Viscosity Mode Example User Scenario

Within HTM's Viscosity Mode, users simultaneously utilize both hands, one to haptically navigate the virtual environment and explore and interact with haptic objects using the Novint Falcon haptic device, while the other hand feels the corresponding temperature of the haptic environment as well as the haptic objects with the virtual environment using the thermal device. In a typical scenario, users navigate the Viscosity Mode interface, interacting with the substance (i.e. haptic sphere), exploring the area surrounding the haptic sphere, and interacting with the haptic boundary around the virtual environment. To the user, the area surrounding the haptic sphere exhibits no haptic feedback – a haptic sensation similar to effortlessly waving one's hand through the air. Likewise, users are able to move through the inside of the haptic object, feeling the sensation of friction, or a resistant movement, relative to the temperature of the substance – a haptic sensation similar to moving one's hand through thick molasses (Viscosity Mode: cold), water (Viscosity Mode: warm), and steam (Viscosity Mode: hot).

3 Method

3.1 Participants

9 participants were recruited from Kansas State School for the Blind in Kansas City, Kansas. Participants were recruited by instructors at the school. There were six female and seven male participants whose mean (M) age was 13 years (Standard Deviation, SD = 2.30). None of the participants had participated in any previous haptic research conducted by the University of Arkansas.

3.2 Apparatus

This study utilized a Dell PC with a 3.4 GHz Pentium R and 1.0GB of RAM. Two haptic devices were used for Training Exercises and Heat Temperature Module (HTM) tasks: a Novint Falcon haptic device and a Thermal Device designed by the HCI research lab at the University of Arkansas. The Novint Falcon was securely fastened to the desktop using adhesive Duck Tape. The Heat Temperature Module utilizes Adobe Flash CS3 software for visual rendering and a C/C++ Novint SDK for haptic rendering. Haptic features were multithreaded, graphics were rendered at 60 Hz, and haptic control was updated at a rate of 1 kHz.

HTM's Viscosity Mode was utilized to collect and analyze user behavior data. Three unique user interfaces were designed for HTM Viscosity Mode, each with different amounts of applied haptic friction feedback and thermal feedback. Table 1 contains a detailed description of HTM's Viscosity Mode.

Multiple surveys and questionnaires were used to assess haptic and thermal recognition, cognitive workload, and user preference. For haptic and thermal recognition, a 5-point Likert scale questionnaire was utilized (e.g. “How difficult was it to move through the inside of the object from 1 [Easy] to 5 [Difficult]?). For cognitive workload, a NASA TLX was utilized which contains six sub-scales measuring mental demands, physical demands, temporal demands, performance, effort, and frustration.All items were rated on a 10-point Likert scale.

3.3 Procedure

Prior to the experiment, each participant was required to listen to, and agree to an Informed Assent Form to participate in the study. Next, each participant was required to complete a Demographics Form. Then, each participant was required to complete a three-part Training Session. Because many participants were unfamiliar with haptic virtual environments, haptic devices, and Thermal Devices, a Training Session was developed to enable users with a foundational understanding and sensibility of haptic virtual environments, the Novint Falcon haptic device, and the HCI Thermal Device. Participants were allowed to revisit or repeat any part of training they were uncomfortable with or unsuccessful at. Once the tester felt that the participant had achieved sufficient training and had successfully completed all preliminary questions and tasks, the participant was allowed to proceed past training. It should be noted that no visualization was provided for any participant – only the experimenter was allowed to watch the visualization of each experiment on an external monitor.

Once a participant successfully completed the Haptic Training Program, three unique interfaces from the Viscosity Mode key task were presented. The sequence of user interfaces were counterbalanced to remove the influence of the learning process as much as possible. Each interface scenario was conducted as follows: A participant listened to a scenario description outlining the interface and goal(s). During this time, a participant could ask any relevant questions – as long as it did not reveal sensitive information regarding how to go about completing the scenario goal(s). Participants were told to perform each task until the time expired. Upon each scenario's conclusion, the participant was asked to complete a NASA TLX cognitive workload questionnaire. Upon each key task's conclusion, a participant was asked to complete a Key Task Questionnaire to obtain user preference and comments in regards to each interface type within the key task. It should be noted that no visualization was provided for any participant – only the experimenter was allowed to watch the visualization of each scenario on an external monitor. Table 1 provides a detailed analysis of the Viscosity Mode key task.

Table 1. HTM Viscosity Mode key task

Viscosity Mode Task **Scenario Time: 30 seconds**	**Description**	There is only 1 subject in the box. Please continue moving left to right, then right to left, back and forth until the time expires. Make sure to touch the wall of the box before you change directions. Your goal is to determine how difficult it is to move through the inside of the object and what temperature the object is.
	Scenario Questions	- Please rate how difficult it is to move through the object from 1 (Easy) to 5 (Difficult). - What was the temperature of the object: Cold, Warm, or Hot? - What did the object feel like?
	Purpose	To navigate and locate an object within the haptic boundary and to distinguish different object viscosities and temperatures.

3.3 User Behavior Measurements

A User Behavior Tracking System (UBTS) was developed in order to collect and store all user cursor behavior throughout each scenario of the key task. The UBTS internally stores Novint Falcon position data (Pos X, Pos Y) at an interval of approximately 20 ms. Each position is marked with a timestamp. Upon a scenario's conclusion, HTM outputs a data file containing the results of the UBTS data.

4 Results

Viscosity Mode user behavior data was examined for each participant and each scenario, a UBTS file contained sample size (n = 1206) data points. As illustrated in Fig. 3, each Viscosity Mode interface consists of two states: 0 (outside the interactive haptic object) and 1 (inside the interactive haptic object).

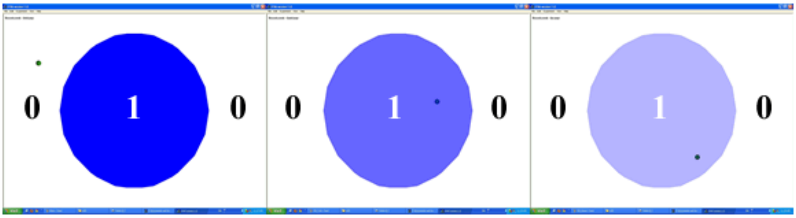

Fig. 3. Viscosity Mode interface state definition

User behavior proportions, per interface, were quantified in Table 2.

Table 2. HTM User Behavior Data Proportions for State 1

Participant	**User Behavior State 1 Data Proportions**		
	Interface 1 (Cold)	**Interface 2 (Warm)**	**Interface 3 (Hot)**
1	60.86%	63.43%	32.42%
2	87.89%	58.79%	57.55%
3	35.57%	28.44%	35.16%
4	26.37%	23.80%	11.19%
5	47.18%	46.43%	27.20%
6	36.07%	18.49%	12.69%
7	53.65%	53.15%	53.07%
8	15.17%	15.09%	0.08%
9	12.94%	2.57%	5.22%

An ANOVA test was conducted to determine significance between Viscosity Mode interfaces for the 9 participants utilizing the user behavior data proportions. Table 3 contains the results of the ANOVA test.

Table 3. User Behavior ANOVA Test Results

F(2,16)	**p**	**Interface 1**		**Interface 2**		**Interface 3**	
		M	**SD**	**M**	**SD**	**M**	**SD**
8.860	0.003	0.418	0.237	0.345	0.216	0.261	0.205

Post-hoc analysis indicated that Interfaces 1 (Cold) and 3 (Hot) were significantly different ($F_{1,8} = 17.7$, $p = 0.0007$) as well as Interfaces 2 (Warm) and 3 (Hot) were significantly different ($F_{1,8} = 5.07$, $p = 0.0387$). However, Interfaces 1 and 2 were not significantly different ($F_{1,8} = 3.82$, $p = 0.0684$).

5 Discussion

This study showed that differences in the amount of haptic feedback result in significant differences in user behavior. In HTM's Viscosity Mode, the amount of haptic feedback, or friction, decreases from Interface 1 (Cold) to Interface 3 (Hot). Likewise, as seen in Table 3, user behavior proportion means (μ) decrease from Interface 1 to Interface 3. The initial explanation can be correlated to Viscosity Mode's haptic feedback (i.e. friction).

As a user moves through the inside of the haptic object, the amount of friction would directly affect how quickly the user's haptic device can move. Therefore, one can reason that higher amounts of friction would result in the user moving more slowly through the haptic object – leading to higher proportions of haptic interaction (State 1). Likewise, lower amounts of friction would result in the user moving more quickly through the haptic object – leading to lower proportions of haptic interaction (State 0). Therefore, it can be reasoned that stronger levels of friction feedback results in higher interactive user behavior proportions. As a real world example, imagine dragging your hand - for the same distance - through honey versus effortlessly moving your hand through air; your hand would remain in the honey for a greater proportion of time due to the high amount of friction applied to the your hand as it moves.

Results also indicated that Interface 1 and 2 were not significantly different, however; Interface 1 and Interface 2 were significantly different from Interface 3. Of the three interfaces, Interface 3 has the lowest level of friction, a sensation akin to saving your hand through water vapor. It is possible that minimal thresholds of friction haptic feedback can be established for a desired level of minimum user interaction data proportions. To establish such desired user behavior thresholds would require further research.

6 Conclusion

This study examined haptic user behavior within the Heat Temperature Module, a haptically enhanced science learning system for learners with severe visual impairments. The overall goal of this research was to advance haptic user interface research in the goal of maximizing ease of use in the domains of haptic interaction and haptic user interface design for both sighted and visually impaired users. Results indicated that higher levels of haptic friction feedback result in higher user interaction proportions of data. Results also suggested that friction feedback thresholds can be determined to establish minimum user interaction data proportions with haptic interface objects, however; more research is needed to establish such thresholds.

References

1. Basdogan, C., Ho, C., Srinivasan, M.A.: Virtual environments for medical training: Graphical and haptic simulation of laparoscopic common bile duct exploration. IEEE/ASME Transactions on Mechatronics 3(6), 269–285 (2001)
2. Brewster, S.: The impact of haptic touching' technology on cultural applications. In: EVA Conference Proceedings, pp. 1–14 (2000)

3. Brooks, F.P., Ouh-Young, M., Batter, J., Kilpatrick, P.: Project GROPE - Haptic displays for Scientific Visualization. Computer Graphics (Proc. SIGGRAPH 1990), pp. 177-185 (1990)
4. Burdea, G.C.: Haptic Sensing and Control. In: Force And Touch Feedback For Virtual Reality, pp. 13–40. John Wiley & Sons, New York (1996)
5. Christensson, J.: Individualising Surgical Training in a Virtual Haptic Environment - Design of flexible teaching strategies to support individuals (Master's thesis). IT University of Göteborg, Göteborg, Sweden (2005)
6. Christodoulou, S.P., Garyfallidou, D.M., Gavala, M.N., Ioannidis, G.S., Papatheodorou, T.S., Stathi, E.A.: Haptic devices in Virtual Reality used for Education: Designing and educational testing of an innovative system. In: Proceedings of International Conference ICL 2005 (Interactive Computer Aided Learning), Villach, Austria (2005)
7. Gunther, E., O'Modhrain, S.: Cutaneous Grooves: Composing for the Sense of Touch. Journal of New Music Research 32(4), 369–381 (2003)
8. Hubbold, R.: Collaborative stretcher carrying: A case study. In: Proceedings of 2002 EUROGRAPHICS Workshop on Virtual Environments, pp. 30–31 (2002)
9. Ino, S., Shimizu, S., Odagawa, T., Sato, M., Takahashi, M., Izumi, T., Ifukube, T.: A Tactile Display for Presenting Quality of Materials by Changing the Temperature of Skin Surfaces. In: Proc. IEEE 2nd International Workshop on Robot and Human Communication, pp. 220–224 (1993)
10. Jones, M.G., Minogue, J., Tretter, T.R., Atsuko, N., Taylor, R.: Haptic augmentation of science instruction: does touch matter? Science Education 90, 111–123 (2006)
11. Kilpatrick, P.: The use of kinesthetic supplement in an interactive system (Ph.D. thesis). University of North Carolina, Chapel Hill, NC (1976)
12. MacLean, K.E.: Designing with haptic feedback. In: Proceedings of the IEEE International Conference on Robotics and Automation, pp. 783–788 (2002)
13. McLinden, M.: Haptic exploratory strategies and children who are blind and have additional disabilities. Journal of Visual Impairment and Blindness, 99–115 (2004)
14. Miller, T., Zeleznik, R.C.: The design of 3D haptic widgets. In: Proceedings 1999 Symposium on Interactive 3D Graphics, pp. 97–102 (1999)
15. Millman, P.: Haptic Perception of Localized Features (Ph.D. thesis). Northwestern University, Evanston, IL (1995)
16. Minogue, J., Gail Jones, M., Broadwell, B., Oppewall, T.: The impact of haptic augmentation on middle school students' conceptions of the animal cell. Virtual Reality 10(3), 293–305 (2006)
17. Falcon, N.: Technical Specs (2010), `http://home.novint.com/products/technical_specs.php`
18. Paulu, N., Martin, M.: Helping your child learn science (Technical Report ED331727). US Department of Education (1991)
19. Roussou, M.: Learning by doing and learning through play: an exploration of activity in virtual environments for children. ACM Computers in Entertainment 2(1) (2004)
20. Ruffaldi, E., Morris, D., et al.: Standardized evaluation of haptic rendering systems. Haptic Interfaces for Virtual Environment and Teleoperator Systems. In: IEEE VR, pp. 225–232 (2006)
21. Sallnas, E.L., Rassmus-Grohn, K., Sjostrom, C.: Supporting presence in collaborative environments by haptic force feedback. ACM Transaction on Computer-Human Interaction, 461–476 (2000)

22. Samur, E., Want, F., Spaetler, U., Bleuler, H.: Generic and systematic Evaluation of Haptic Interfaces Based on Testbeds. In: Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego, CA (2007)
23. Sauer, C.M., Hastings, W.A., Okamura, A.M.: Virtual environment for exploring atomic bonding. In: Proceeding of Eurohaptics, pp. 232–239 (2004)
24. Swindells, C., Maksakov, E., MacLean, K.E., Chung, V.: The role of prototyping tools for haptic behavior design. In: IEEE Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems (HAPTICS 2006), Washington, DC (2006)
25. Yu, W., Brewster, S.: Evaluation of multimodal graphs for blind people. Universal Access in the Information Society, 105–124 (2003)