A Haptic Multimedia Handwriting Learning System

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ABSTRACT

In this paper, we describe a multimedia system for learning handwriting and pronunciation of alphabet letters or characters in different languages. This system provides haptic, audio and visual information according to the desired letter or character chosen by a user. Letters or characters from the Arabic, English, French, Japanese, and Spanish languages have been considered, although the system utilizes an XML-based schema to easily introduce new characters from another language.

Three different modes of learning can be chosen in terms of haptic information: full guidance, partial guidance and a no guidance mode (no haptic feedback). The full guidance guides the user to follow a pre-recorded letter trajectory; whereas in partial guidance, a user can freely follow a letter-drawing path, but if the user deviates significantly, the system automatically brings him/her back to the optimal displayed path. The no guidance mode allows users to perform letter handwriting with only visual information. This system guides users to write a character, in a similar way as a teacher holds a student's hand. Moreover, the character trajectory is displayed as the user is performing it. The results of this system evaluation show its potential as a virtual tool for learning handwriting.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces and Presentation**] Multimedia Information Systems - *evaluation/methodology.*

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Haptic I/O, evaluation/methodology*

General Terms: Design, Measurement, Performance

Keywords

Education, Haptic Playback, Haptics, Multimedia, Virtual Teaching

1. INTRODUCTION

As a rule, sensorimotor skill tasks require an established or optimal strategy and a sequence of operations/movements. A person can learn how to carry out a sensorimotor skill task by seeing how an expert or a video does the same task; however, there are certain learning tasks that require a trainer to physically interact with a trainee. Transferring such motor skills can be difficult to describe verbally and therefore, the sense of touch as physical guidance is necessary. Examples of tasks where physical guidance takes place are in learning handwriting, medical procedures, painting/sculpting techniques, and sports. For instance, the teacher can hold the student's hand to show how to write a Chinese character or a letter from the Latin alphabet. Generally, the sensorimotor skill transfer from one person to another is complicated and time-consuming [1].

The haptic technology or haptics seems to hold a lot of potential for learning or training sensorimotor skills. Haptics refers to the emerging discipline that studies the sense of touch and human interaction within an environment via the sense of touch. Haptic sensations allow for multimedia applications, which utilize gesture recognition and force feedback. In addition to traditional media such as audio and video, haptics – as a new media – plays a prominent role in making real-world objects physically palpable in a shared virtual environment and recognizing the physical properties of virtual objects such as shapes, textures, and stiffness. A system where haptic, visual and audio information can be integrated to enhance user learning and whereby users can perform the task as many times as required without the presence of a tutor can positively contribute in learning or training.

The significance of these multimedia systems, which integrate a new modality of learning through force feedback, can be seen as a new teaching tool, for instance, in handwriting for children or beginners in a new language, which make use of different alphabet letters. Preliminary results using haptic-visual systems have shown their potential in helping kindergarten children to control handwriting movements [2]. For adult handwriting acquisition, other systems have been tested with satisfactory results [3, 4].

Handwriting is a complex daily life task that needs attention, memory and cognition, and motor skills [5, 2]. The main features in handwriting are the sequential order of the consecutive strokes and the spatial requirements in the writing pattern. These features can be demonstrated using visual and haptic information, in addition to the letter's phonetics. Moreover, it has been proven that haptic-visual systems are promising for learning [6, 2].

The present paper investigates the possibility of using haptic-audio-visual playback for learning handwriting as a multimedia teaching tool. Ten Japanese character trajectories were tested with six different participants. After training with the ten characters, the subjects were asked to draw all characters in a different order. The results showed that the participants were able to first learn how to write them and secondly, reproduce them without any haptic or visual guidance. The remainder of this paper is organized as follows: Section 2 presents related work using the haptic modality in learning tools. In Section 3, the haptic learning system architecture and components are described. Section 4 discusses several algorithms that were incorporated in the system design. Section 5 presents the performance analysis and section 6 highlights our findings and potential future directions.

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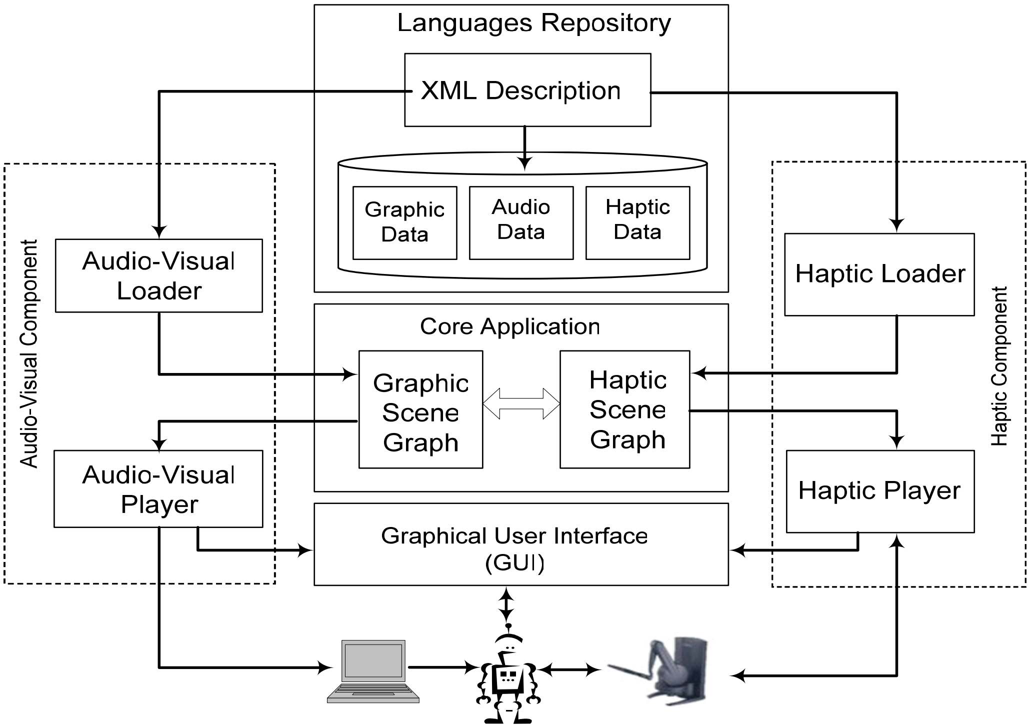


Figure 1. The haptic learning system architecture

2. RELATED WORK

Previous research has paid special attention to haptic-visual systems for teaching handwriting. We can find examples for Japanese characters [3, 7], Chinese characters [4] and Latin alphabet letters [2]. In general, this kind of systems is based on haptic playback. Haptic playback refers to the ability to display prerecorded haptic information using a haptic interface. Ideally, both information regarding an expert's positions and force interactions should be displayed simultaneously; however, it is impossible to display both at the same time. Because trajectory or position information is more useful for teaching handwriting skills, most of the systems have focused on displaying trajectories saved through a haptic device.

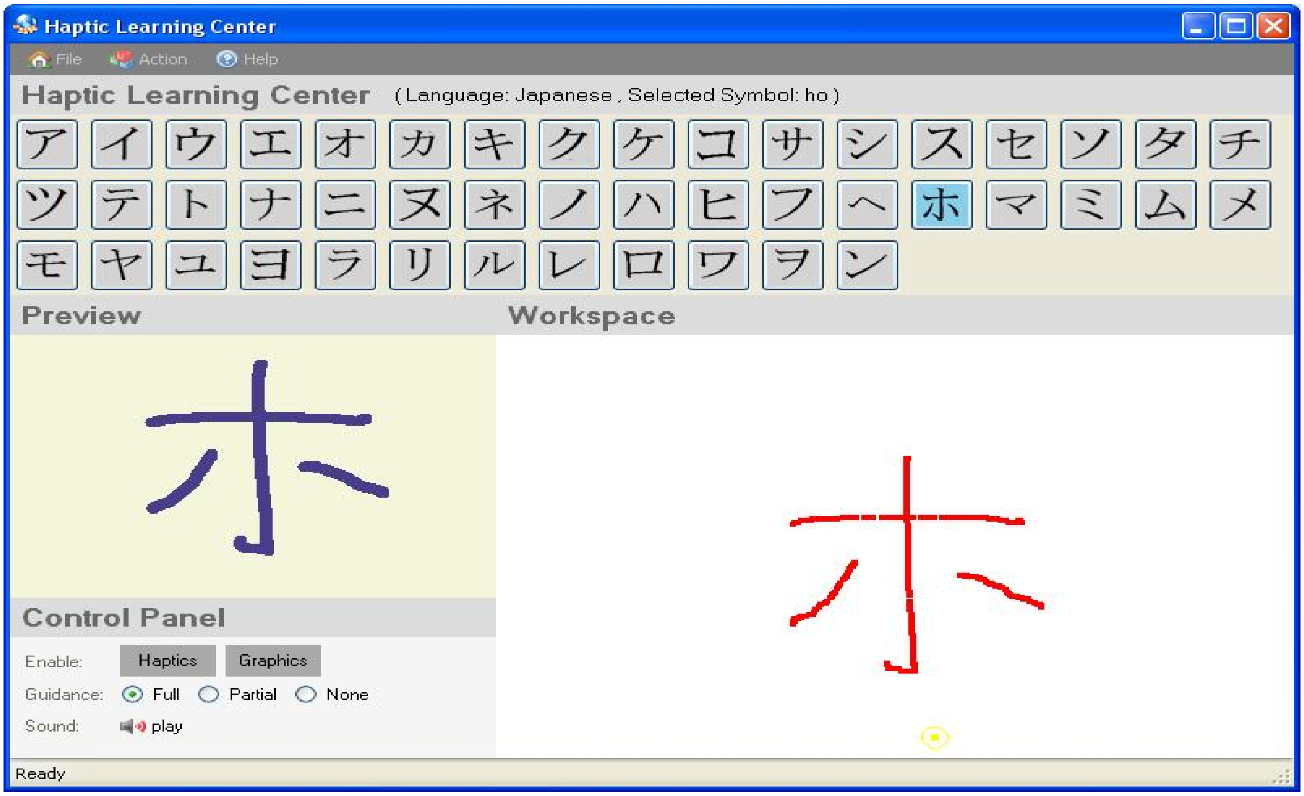
In 1998, in one of the first works, the researchers showed that there was some positive effect on learning one Japanese character from the kanji writing system when using force feedback [3]. The more the student trained, the more similar the character was to the drawing letter defined by a teacher. In [7], the I-TOUCH system is described and a preliminary evaluation was carried out by using one Japanese character. Users found the system useful, although there was not a noticeable difference between providing haptic-visual information or only visual information for the chosen character when recognizing the unique character.

As in Japanese, Chinese characters are usually formed by different strokes that have to be performed in a certain order. In [4], to guide users to the beginning of the stroke, five different models of assistance were distinguished. These models were defined according to different forces, stiffness, or damping. The initial results with six users were satisfactory and showed their improvement during the learning process. However, the number of Chinese characters involved in the experiments is not mentioned. Another work has shown the suitability of adding force-feedback for handwriting acquisition in 22 six-year old children [2]. The movement time and the number of velocity peaks were analyzed through the proposed haptic-visual system, called Telemaque. The results showed that the Telemaque system helped children to control movements for better handwriting performance of four cursive letters.

Unlike these systems, our system provides a Graphical User Interface (GUI) where the user can choose any letter or character from the Arabic, French, English, Japanese and Spanish languages. The system provides haptic, visual and audio information for each letter. The user can select the learning mode: full guidance, partial guidance, or no guidance modes. Moreover, since this system is XML-based, other language alphabets can easily be introduced. The system is also independent from the haptic device used for recording the haptic data, that is, other haptic devices complaint with the HAML system can be used to play back the haptic stimuli that are available in the system repository [8]. At present, the system can be used with any of the PHANToM devices [9] and the MPB Freedom 6S device [10].

3. HAPTIC LEARNING SYSTEM

The haptic learning system comprises four major components: the language repository, the audio-visual player, the haptic player, and the GUI. Figure 1 presents an overview of the haptic learning system architecture.



Haptic Learning Center (Language: Japanese , Selected Symbol: ho)

Enable: Haptics Graphics

Guidance: ● Full ○ Partial ○ None

Sound: play

Ready

Figure 2. A snapshot of the haptic multimedia handwriting system

The following are brief descriptions of each component. A snapshot of the application GUI is shown in Figure 2.

- *Language Repository:* The language repository contains the study material presented to the learner, including the symbol images, the pronunciation files, and the haptic stimuli (position trajectory to draw a character). The repository contents are made visible to the outside world using an XML-based description that is structured into three main schemes: the metadata, the alphabets, and the haptic device (Figure 3). The metadata scheme describes the language name, audio files extension, images extension, the author's information (such as the author's name, address, company, etc.), and intellectual property. The alphabet scheme contains a list of items, each representing a symbol in alphabetical order. The item content is a string that refers to the name of an alphabet letter in the language that is used to refer to the audio, image, and haptic files of the alphabet. Finally, the haptic device scheme lists the observations and spatial characteristics of the haptic device used to capture the haptic stimuli for the alphabet symbols. Information about the device includes, but is not limited to device stiffness, workspace dimensions, haptic refresh rate, and force range.
- *The Haptic Player:* The haptic player supports three modes of operation: the recording mode, full guidance playback mode, and partial guidance playback mode. In the recording mode, the haptic player is capable of retrieving, filtering, and storing the data sent from the haptic device in a local database. Through the recording of haptic data, the student performance can be evaluated quantitatively by finding errors in positions and forces between the student writing and the reference representation of the corresponding alphabet. The full guidance playback mode can be used with beginners to lead them through the writing of the alphabet. The system fully guides the student. In the partial guidance mode, the player checks if the user movement diverges significantly from the desired path and applies partial forces to bring him/her back to the correct path. As long as the student is following the correct stroke path, the device will not intervene with the subject's hand movement. Finally, it is worth mentioning that the haptic player is device independent in the sense that the recorded haptic stimuli can be played on theoretically any haptic device. This is achieved by comparing the recording device characteristics (in the XML description of the recording device) and the playback device characteristics and eventually applying the necessary transformation on the recorded data before sending it to the haptic device.
- *The Audio-Visual Player:* When the student selects a particular character, the core application will automatically invoke the graphic player to plot the character symbol in a review area. Moreover, the user can hear the pronunciation of the character independently by clicking on a speaker icon. The student can review the character shape and sound as many times as he/she wants.
- *The Graphical User Interface (GUI):* The main GUI shows a drawing area, a keyboard panel that lists the language alphabets, and a control panel. The control panel defines the level of guidance (full, partial, and no guidance), and the learning modalities that are to be incorporated in the mode (such as audio, video, or haptic). Additionally, the GUI enables the student to load language packs (currently the application

supports Arabic, English, French, Spanish, and Japanese Katakana) by browsing the XML description file for the corresponding language. Afterwards, the student can practice the handwriting of the alphabets and optionally record his/her performance using the recording button. The student can plot the recorded and the desired character paths on the same screen to graphically evaluate his/her performance.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
<Language Name="Japanese_Katakana" Flow="left"
xmlns="urn:language">
      <MetaData>
           <AuthorName> Steve </AuthorName >
           <ContactInfo> steve@msn.com
      </ContactInfo>
           <Copywrite> LGPL </Copywrite>
           <CreationDate> 06-05-2007
      </CreationDate>
      </MetaData>
      <HapticDevice>
           <DeviceName> Phantom </DeviceName>
           <Workspace> 160X120X0 </DeviceName>
           <MaxForce> 3.0 </MaxForce>
           <DOF> 3 </DOF>
      </HapticDevice>
      <Alphabets>
           ...
           <Item Name="ka" />
           <Item Name="ki" />
           <Item Name="ku" />
           <Item Name="ke" />
           <Item Name="ko" />
           <Item Name="sa" />
           ...
      </Alphabets>
</Language>
```

Figure 3. A snapshot of XML language description

4. ALGORITHMS

In this section, we describe several algorithms that are incorporated in the application design. These algorithms are related to the haptic rendering to provide enhanced haptic rendering.

4.1 Haptic Virtual Whiteboard

To enrich the interaction and the haptic feedback qualities between the learner and the tool, a virtual haptic-based whiteboard has been simulated. The user is able to feel a 'touch' whenever the device avatar collides with the virtual whiteboard and use this information to start handwriting. The contact between the virtual whiteboard and the haptic device stylus is simulated by applying an impeding force against the direction of movement, when the user tries to penetrate the whiteboard plane. The reaction force from the virtual whiteboard plane can be computed as in [3]:

$$F=\begin{cases}0 & X>Xp\\ g\times(Xp-X)^3+K\times(Xp-X) & X\le Xp\end{cases} \qquad (1)$$

X represents the position coordinates of the haptic device stylus along the normal direction of the paper plane whereas Xp is the plane position along the same direction. The parameters *g* and *K* are constants to define the stiffness and elasticity of the virtual paper (and are to be determined by trial and error as they depend on the haptic device in use). For instance with the Phantom Omni device, two values that work properly are *g*=0.04 N/cm^2 and *K*=0.8 N/cm.

4.2 Partial Guidance Playback

At a relatively advanced stage in the learning process, the user might need partial help in hand movement along the desired handwriting path. This is where the partial guidance can be used. The partial guidance algorithm works as follows: first, the offset between the user's startup position and the desired startup position eliminates translational errors. The user's starting point is defined as the first contact point with the virtual paper. Then, while the user is drawing the character symbol, the error between the device position and the desired one is computed along the paper plane using the Mean Square Error (MSE). For example, the error along the Z-axis will not be considered if the virtual paper is in the XY-plane. Third, the total accumulated error is calculated and compared to a threshold that reflects the level of guidance. Any user can specify the guidance threshold. Finally, if the error goes beyond the threshold, a force will be computed and sent to the device to convert the user's movement back to the desired path. The accumulated MSE can be computed using the following equation (equation 2):

$$MSE(n)=\frac{\sum_{i=1}^{n}\sqrt{(X_{ip}-X_{id})^2+(Y_{ip}-Y_{id})^2}}{n} \qquad (2)$$

Where the coordinates (X_{ip},Y_{ip}) represents the current position of the device whereas (X_{id},Y_{id}) are the desired position coordinates. The parameter *n* represents the number of points from the startup point up until the current point.

4.3 Move-to-Departure Algorithm

One problem we encountered during the experimentation was the impulsive and sometimes unstable movement of the haptic device when starting the full guidance haptic playback. The reason was that the difference between the initial device position (the user's hand position) and the startup playback position can be very large and may result in abrupt forces. Therefore, we defined an algorithm that makes the device move smoothly from its current position to the startup position of the stimulus. The forces sent to the device decreases as the device becomes closer to the destination, thus resulting in a decelerating movement of the device towards the startup position. This makes the movement more realistic.

5. PERFORMANCE ANALYSIS

In this section, we present the experimental description and results for the proposed learning system.

5.1 Experiment Description

For the purpose of the evaluation, six participants performed ten different Japanese characters from the writing system called katakana. The participants had no Japanese background before. The haptic device used was the PHANToM Omni device [9]. Firstly, the users became familiar with the system by performing different letters three times. Secondly, they performed ten Japanese characters, twice, in the same order as shown in Figure 4. The following day, they were asked to reproduce the learned characters on a sheet of paper. The characters to be written were presented in a different order (written by a Japanese writer) from the learning trial. The Japanese writer, acting as a teacher, watched the participants write the characters and marked their results. He watched whether any break were performed, the correct sequence, and evaluated the written character.

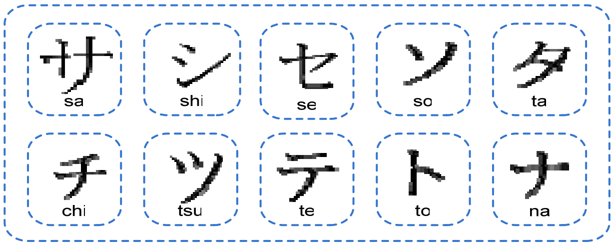


Figure 4. Ten Japanese characters used from the Katakana writing system

5.2 Results

This section shows the results of the comparison between the character trajectories performed by the system and the played-back trajectory for each user. Moreover, the evaluation when writing the characters on paper is also described.

5.2.1 Trajectory results

To evaluate the quality of the reproduction of the character trajectory, the MSE is computed. The MSE represents the mean error between the played-back trajectory and the recorded trajectory in the system. It is computed in the same way as in equation (2) but with the Z component also incorporated. Figure 5 presents the average MSE for the six participants. The average MSE for all the characters was only 4 mm. This implies that the system was able to guide the subjects along the optimal character's trajectory with very high playback quality. In all cases, the MSE did not exceed 5.8 mm.

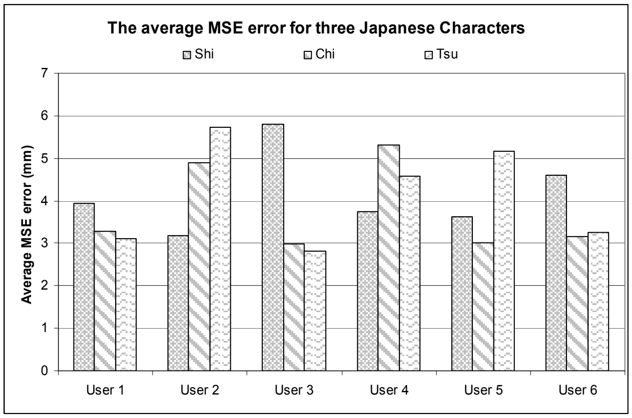


Figure 5. The average MSE error for three Japanese characters

Furthermore, the force variations over time are plotted in Figure 6. The diagram shows how smooth the forces were to guide the user, when playing back the 'chi' trajectory. There are no abrupt changes in the force magnitudes. Therefore, we conclude that in all cases, the haptic device remained stable and the haptic playback was adequate.

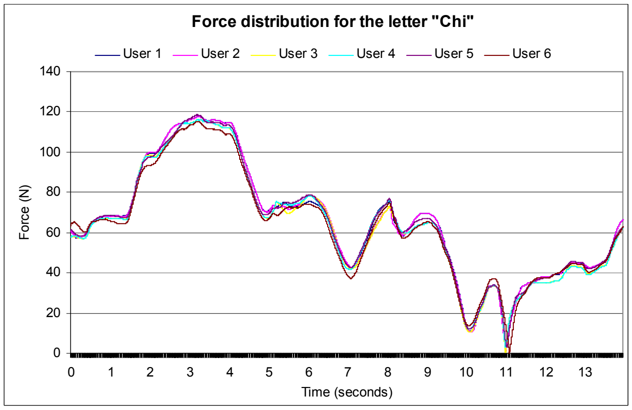


Figure 6. The force magnitude variations of the letter "Chi" over time

5.2.2 Evaluation

During the evaluation, users praised the system and found it helpful and easy-to-use. Three users were able to correctly write the 10 characters, two of them wrote one character incorrectly and only one user wrote two characters incorrectly. Nearly all users found problems when writing these four characters: "chi", "tsu", "ta" and "sa". They could not remember the correct stroke order for "chi" and "tsu", because of their similarity (Figure 4). The characters "chi" and "ta" were also difficult to write in the correct order and with the appropriate number of strokes. Only one user made a break when writing a stroke in two different characters.

Because the training was based on only two trials in one day, and the evaluation was carried out the following day, we believe that the evaluation was somehow dependent on the users' memory skills. Despite that, the results show that this system has potential for handwriting alphabets of different languages. Interestingly, some users were also able to remember some of the characters by their sound.

6. CONCLUSIONS

The objective of the proposed research is to show that incorporating a haptic sensory modality increases the learning ability and fluency of handwriting alphabets in various languages. The system guides users to write a desired character, and the user's motion is displayed while virtually writing on the haptic screen. Moreover, users can play the audio information of the character pronunciation.

As per future work, we plan to integrate audio or text-message help with information about any rule for handwriting sequences. Additionally, another future avenue is the ability to create haptic stimuli that correspond to complete words and thus the system will be able to guide students on how to write words, and eventually sentences, rather than just one character at a time. For instance, the user can type a text and the system will automatically generate the corresponding haptic stimulus. In some languages, such as Chinese and Japanese, the temporal pattern (i.e. timing and velocity) of each stroke is crucial, because of this, we will also consider it as criteria in our future evaluation.

7. Acknowledgements

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