Haptic Handwriting Aid for Training and Rehabilitation

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Abstract *This paper reports a method of controlling a user's hand through the process of writing. Developed predominantly for enabling users to re-learn the skill of writing after a stroke, the process could also be used for teaching children hand / eye coordination, motor skills, movement and position awareness in writing. Utilising low cost haptic technology and custom control software, the system has the potential to increase writing skills in stroke sufferers in the privacy and comfort of their own home.*

1. Introduction

Due to the ever-decreasing cost of haptic technology, new areas of research in the field are becoming practicable. The ability to write is something many of us take for granted. Unfortunately however, stroke sufferers will often lose this essential skill and many are unable to write again. Stroke affects approximately one hundred and forty people per hundred thousand (14%) with differing levels of severity. Statistics show that the incidence of stroke doubles every ten years after the age of forty-five. Stroke is the leading cause of disability, two thirds of patients survive stroke but have residual disabilities.

It has been shown that early and intensive physiotherapy can improve the quality of life for stroke victims. Generally therapies must be customised to each patient for best results.
Utilising haptic force reflecting hardware combined with intelligent control software, our haptic handwriting system allows users with poor motor skills to be guided through the process of letter formation. A character, word or string of words can be entered into the Haptic Handwriting Aid (HHA) allowing a stroke victim to reproduce useful words. This method of haptic training has the potential to stimulate re-learning in the brain of stroke victims with obvious cost benefits to user and health care industry.

2. Previous Work

Surprisingly, little work has been completed in the field of technology enhanced handwriting skill recovery after stroke. Haptic research into gait re-learning has occurred with some success [2]. Haptic muscle strengthening training is also gaining acceptance in physiotherapy practices [3]. When talking to stroke victims however, many state the loss of handwriting ability as one of their biggest disabilities [5, 6].

Using haptic technology based on the Phantom line of products from Sensable [4], Jeng-sheng Yeh *et al* have constructed a Chinese painting and calligraphy based simulation engine [1]. This engine is promising in the field of remote art but is limited in its application to handwriting re-learning of stroke patients. Shi *et al* [7] have developed a tablet and a pressure-sensing pen enabling a user to write calligraphic characters in two dimensions. The disadvantage with this system is the lack of kinaesthetic feedback to the user. Baxter [8] uses haptic technology both as the input and output device. The force transmitted to the user is related to the penetration depth, tilt angle, and velocity of the modelled object. Baxter does not take into account frictional forces and once again the device is not primarily designed as a guide for a users hand as much as it is an input to the modelled system.

Generally, after a stroke, sufferers are affected by infant like motor skills that effect postural stability and control, hand eye coordination, pencil and grip skills, movement and position awareness and visual and motor perception. One method of re-learning the muscle memory required for handwriting is to guide the users hand through the required motions of generating characters. This process is generally achieved through a rigorous routine of physiotherapy. The use of haptic technology for rehabilitation of the disabled has been shown in [9].

Fielding shows that by adding tactile feedback to a computer mouse a significant increase in task performance was noted [9].

Requiring at least 800Hz for faithful kinaesthetic feedback, a haptic system must be capable of updating positional information *at least* that fast [10]. To put this into comparison, the human eye can only comprehend a refresh rate of between 30 – 50Hz.

3. System Configuration

With cost being one of the major prohibitive factors in new technology acceptance, the Phantom Omni from Sensable was chosen as the input / output device. The Omni is portable, rugged, easy to interface and most importantly its low cost makes it ideal for end user operation.

The treatment of a stroke victim costs the health system upwards of $AU60,000 [11], rehabilitation devices have to be cost effective in order to be accepted by the medical community.

The Phantom Omni is connected using an IEEE 1394 (Firewire) interface to a personal computer and is controlled via custom software. Even relatively low-end laptops with built in firewire interfaces are supported (figure 1).

Due to the relatively high processor demands of controlling the haptic loop at 1000Hz, a reasonably modern processor is required to run the haptic handwriting aid software. Testing has shown that a 1.8Ghz Pentium 4 is more than capable in this respect.

Figure 1 Phantom Omni being used on a Laptop

The Omni device allows for approximately 0.05mm positional reporting resolution and exerts a force of up to 3.3 Newtons on a user's hand, in a workspace of approximately 160 x 120 x 70 mm. It should be noted that this workspace has been reduced to allow a usable wrist movement while writing.

4. Control Algorithm

The software driving the haptic handwriting aid is constructed of four main parts. Sensable 3D touch SDK, OCX (OLE Control Extension), control algorithm and GUI (Graphical User Interface). The Sensable 3D touch SDK will not be covered in this paper, as information is readily available.

The software has been developed to operate cross platform. The GUI and control algorithm code will run on Windows, Linux and Macintosh platforms. Figure 2 highlights the flow of information between the four main software components and the haptic device.

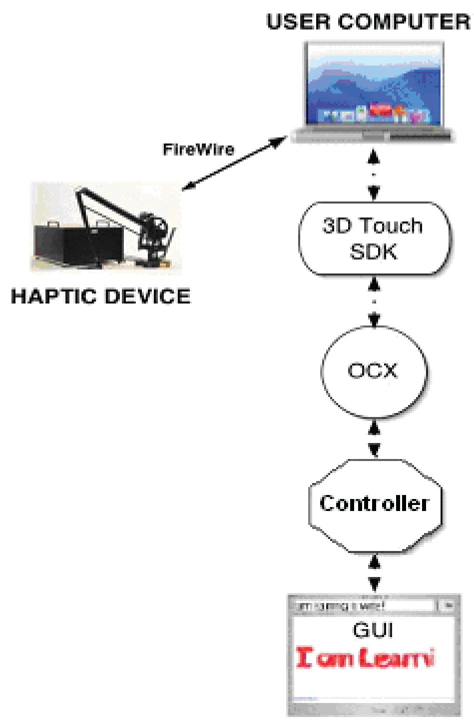

Figure 2 Hardware connection and control algorithm layout

4.1 Software Fusion

In order to increase the effectiveness of haptic control in our handwriting task, a standard control methodology needed to be implemented. This standard allows the control of the Phantom Omni without significant coding overheads. To create the required flexibility without sacrificing functionality we were required to design new software that built upon the original HD and HL libraries used by Sensable's haptic devices. This higher-level language was able to function with most other Windows based software on the market; it also fitted the requirement of being able to communicate via TCP/IP, RS232 and UDP/IP. The software is also capable of taking advantage of every current property the haptic device possesses.

The application called for low cost haptic devices that could be integrated into a wide range of markets. As a result, the Phantom Omni range of haptic devices (from Sensable) was chosen. Significant time is required to learn the essential Application Peripheral Interfaces (APIs) for programming Sensable devices and C++.

It becomes clear that to open haptics up as a standard, the implementation of a custom OCX is required. This allows nearly any language from Basic to HTML to interact with the haptic world.

As a result an OCX has been developed that can call all the Sensable functions, pass data via multiple protocols, communicate with force/torque sensors and be programmed to pass position, velocity, acceleration and force data to any desired application.

4.2 Device Control

Generally a Phantom Omni is designed as a positional output device and force input device. This task requires this process to be inverted i.e. the device will receive positional information in three-dimensions and generate forces in order to move to the desired position. This process required the development of a universal controller that would work with any Omni.

The algorithm was calculated by evaluating the open loop response of an Omni to step, ramp and trigonometric inputs. This yielded a weakness to the open loop system. The Omni suffers from a large percentage of overshoot and large settling time as seen in Figure 4. This caused the device to fail on large positioning steps; this failure was accredited to the percentage overshoot becoming so large that the device exceeds its own force limitations.

In order to compensate for this a PD (Proportional Differential) controller is introduced that decreases the overshoot and reduces settling time to acceptable boundaries. Figure 3 shows the Block diagram of the final system controller.

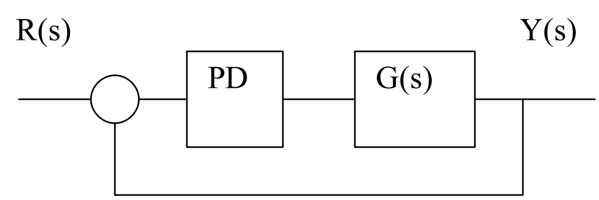

Figure 3 Systems block diagram

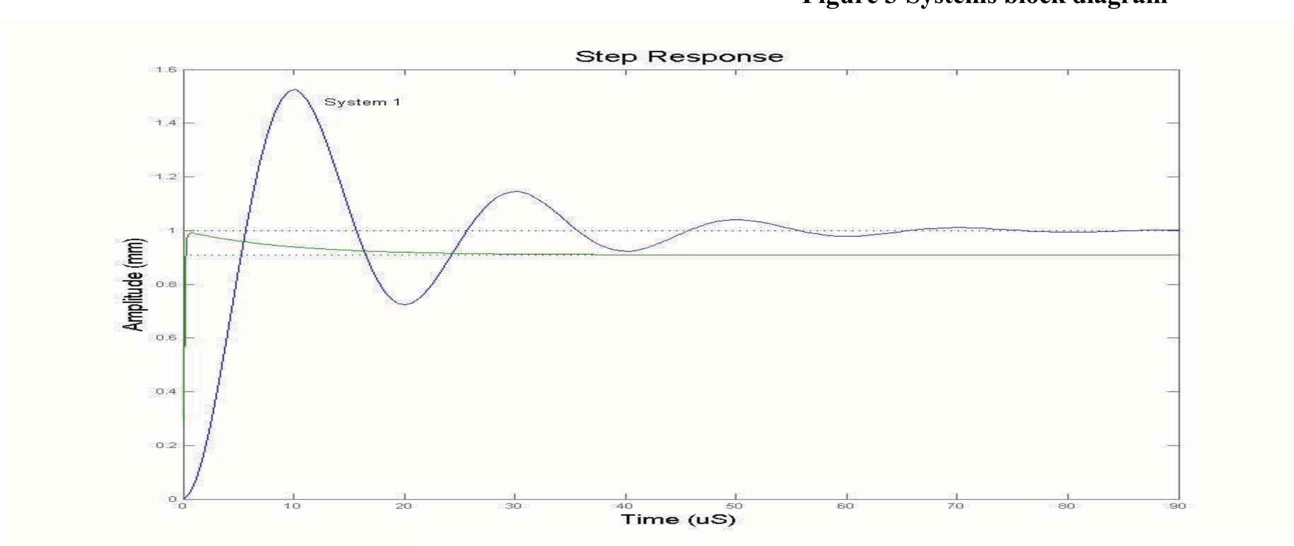

Figure 4. Step Response of HHA system

R(s) is the desired position in millimetres and Y(s) is the actual position in millimetres. Equation 1 defines the closed loop system, where k_1 is the user defined gain of the proportional controller and k_3 is the differential gain. The effect of the closed loop PD controller can be clearly seen in Figure 4 (max amplitude of 1).

$$G_{cl}(s) = \frac{(k_1 + k_3 s)16}{156s^2 + (20 + 16k_3)s + 16 + 16k_1} \quad (1)$$

Analysing the closed loop response shown in Figure 4, it is evident that the new controller has a steady state error when compared to the open loop response. This is filtered in software as a constant error calculated by Equation 2.

$$e_{ss} = \frac{1}{1 - k_1} \quad (2)$$

Placing the control algorithm into the system allows fast positional relaying to an Omni device, resulting in sharp accurate positional responses.

5. Visual Representation

The Graphical User Interface developed for the Haptic Handwriting Aid is minimalist and simple to use. When started, the user is presented with an input text field, a speed selection and a run button.

The input field can be a single character, a word or a string of words. Once the desired text is entered, a write speed is selected.
This option allows the user to start the hard task of learning to write slowly and then work up to a faster pace as motor skills improve.

When the run button is selected, the interface waits a short period before beginning the control of the haptic device, and in turn guiding the user's hand through the motions required to form individual letters.

When the program detects that the haptic workspace is nearly expended, the device starts the next character by moving to the left and scrolling the display.

Incremental accuracy is also displayed to the user. This display can be used to plot progress over time and determine the setting for write speed selection.

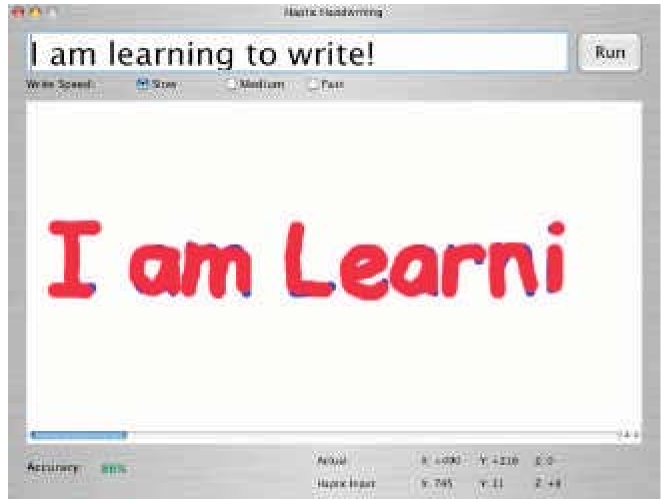

Figure 5. GUI developed for Haptics Handwriting Aid

Finally, the actual and haptic input pixel positions are displayed to the user. This may aid technologically literate persons to understand the basic principles of the device. Z axis information is especially important as it determines pen pressure against the writing surface.

It should be noted, that the handwriting used for comparison is currently based on the Comic Sans MS font. This font was selected, as it closely resembles the text used in many writing books based on the Zaner-Bloser style of handwriting. D'Nealian style writing can also be selected by italicising the font in the input field.

6. Results

While in the early stages of development, the Haptic Handwriting Aid has shown promise. Based on in-house testing of able bodied users, the system is able to control a users hand through the motions required to form letters.

The required haptic control rate of 1000Hz has been exceeded by 200Hz using the current control system. Control of the system has been increased allowing for sharp non-fluid motions to be replicated, as required for certain aspects of writing.

Able-bodied users of the haptic handwriting aid achieve a score of between eighty-five and ninety-seven percent compared to that of the original text. The high percentages represent an ability to form the letters required for handwriting tasks while being guided by the haptic system.

7. Discussions and Conclusion

While relatively simple in concept, the Haptic Handwriting Aid has the ability to significantly increase sensory input to stroke patients at a low cost. Initial trials with able-bodied users have shown the effectiveness of the hardware in controlling a users hand through the motions required to generate letter and word groups.

Research into optimal pen diameter is currently underway. As it stands, the Phantom Omni consists of a 20mm diameter stylus. While good for stroke patients, this diameter is too large for training young writers.

The logical progression from a haptic recording system is to use the stroke victim's original handwriting for source material. Once traced into the system, the HHA could be trained for a specific patient.

The OCX, Controller and GUI have all been developed in-house allowing flexible adaptation of the system to the specific needs of stroke sufferers including left and right hand variations.

The ability to use commercial off the shelf technology has allowed the system to be developed with minimal expense. With the average stroke costing the Australian health care industry $AU60,000 the cost of the HHA is minimal in comparison, costing less than AU$10,000.

It is hoped that the haptic handwriting aid interface will stimulate re-learning in the brain, recovery of muscle strength and ultimately achieve functional goals that improve independence.

8. Future Work

Current work is focussed on improving the functionality of the user interface. The introduction of three more axes to the HHA will allow pen slant and hand position to be controlled but it also increases the complexity of the control algorithm. Currently only the Phantom 1.5 and 3.0 have a six-degree of freedom capability. These devices are prohibitively expensive for the target market. As demand increases and manufacturing costs decline, we expect to see a haptic interface similar to the Omni with a six-degree of freedom capability. With the introduction of more axes, the current control method of 2.5D (X and Y plus height or pressure) will become obsolete. The data set used for controlling the haptic device through the hand movements for constructing characters will no longer be based on standard fonts. It is expected that this problem will be solved using a learning algorithm. The HHA will be taught correct hand positioning and letter formation by a skilled writer using a haptic device for input. All six axes will be recorded and stored for a particular character. Six PID equations will be calculated during each cycle and the results sent to the haptic device for force output.

The potential for inputting a signature is also of great benefit to many stoke sufferers.

The adaptation of the HHA to young writers in primary or grade school has a tremendous appeal. Work will continue on this area with a focus on "fun" graphics and an integrated curriculum.

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