Machine-mediated Motor Skill Training Method in 
Haptic-enabled Chinese Handwriting Simulation System

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Abstract- Training of motor skill through machine-mediated method is a promising way to improve complex dexterous manipulation skill. New method of fusion between human motor skill and machine capability is studied to transfer skill from expert to novice. Haptic-enabled Chinese handwriting training system is established as a benchmark platform for studying learning and transfer of motor skill. Perceptible element of haptic skill is proposed to model human motor skill. Four rules of machine-mediated training system are identified according to human’s skill learning characteristics. Architecture of a hierarchical hybrid control training system is proposed based on the learning rules. Phantom desktop is used as the haptic interface and haptic-visual feedback is developed for three training modes, which includes facsimile mode, transcribe mode and reciting mode. Human subject experiments validate the proposed training rules. Fusion of human skill and machine capability by haptic-enable multiple signal feedback system is proved effective to train novice to get familiar with Chinese character handwriting skill.

Index Terms – Motor skill, Chinese handwriting, haptic training

I. INTRODUCTION

Motor skill is defined as the ability to execute a movement in an optimal fashion, or can be defined as an activity of a person involving a single or a group of movements performed with a high degree of precision and accuracy [1]. Chinese handwriting simulation is a good benchmark for studying motor skill learning because various skills are involved in order to coordinate motor output with sensory feedback for producing perfect strokes. The sensory-motor skills of wrist and fingers need to be trained over a long period before the structure and sequence of strokes become familiar. It is valuable to explore ways to accelerate the learning process.

There are mainly three problems in order to establish effective machine-mediated training systems:

➤ How to model human haptic motor skill and its learning mechanism during manipulation such as handwriting?
➤ What are fundamental requirements for a satisfied training system?
➤ What kind of modeling and rendering algorithm is effective for haptic assisted skill training?

Function of haptic training during motor skill learning has been explored by pioneers. Fitts et al. defined three stages of learning: cognitive, associative, and autonomous [2]. It is stated that haptic training could accelerate and improve subjects’ progress through the first two stages [3]. Feygin et al. investigated the use of haptic information for learning a complex 3D trajectory [4]. Kikuuwe et al. utilized force information to teach a student on the correct method of pressing with a finger [5].

Yokokohji et al. developed a WYSIWYF interface and used record and play method to transfer recorded expert’s skill to students [6]. Solis et al used reactive robot technology to teach handwriting and claimed their method to be proven highly effective [3]. Henmi et al. reported transfer of skill to teach Japanese calligraphy and they proposed need for further experiments [7]. Teo et al. established a Chinese handwriting training system [8], in which the learning process is decomposed into motion guidance and path constraining.

From literatures it becomes evident that modeling of human haptic skill during handwriting process is an open problem. Unified rules for combining various force rendering methods to construct machine-mediated training system are still absent [9-11].

The goal of this paper is to explore fusion method of human skill and machine capability to assist motor skill learning of human’s handwriting process. Furthermore, we
hope to identify function and capability of haptic training during complex motor skill learning process.

The remainder of the paper is organized as follows. Section 2 gives learning mechanism of handwriting motor skill and architecture of machine-mediated training method. Section 3 introduces system prototype, training method and evaluation criteria. Section 4 discusses experiments results. Section 5 gives conclusion and future work.

II. MACHINE-MEDIATED TRAINING METHOD

A. Human motor skill learning characteristics

The motor learning is an iterative process of improving the motor performance by executing movements, identifying errors, and correcting those errors in subsequent movements. The motor learning and control concerns the behavioral, biomechanical and neural bases of development, acquisition, and control of functional movement skills [3]. Furthermore, other characteristics during learning can be identified includes: learning by doing, trial and evaluation, skill reinforcing mechanism etc [12].

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Based on human haptic skill, perceptible elements combination and status switch model is proposed to represent haptic skill of handwriting process. Sequential and shape training are two fundamental components for haptic handwriting training. Task planning and status series during handwriting are established based on status switch method. Evaluation criteria are proposed for each perceptible element [12].

B. Rules of machine-mediated training system

Based on human skill learning characteristics, design rules are proposed to describe fundamental components of a machine-mediated motor skill training system.

Rule 1 --- Function of the training system should focus on requirements in cognitive and associative stages

In the three stages proposed by Fitts [2], haptic training could accelerate and improve subjects’ progress through the first two stages.

In the cognitive stage of learning, especially with a complicated motor task, haptic training may significantly improve learning by allowing the subject to make a connection more easily between the verbal instruction and the motor requirements.

In the associative stage, haptic training may also help during this second stage of learning by directly showing the subject how to accomplish the task.

In the autonomous stage, haptic training may not be effective, since any form of additional or augmented feedback could be detrimental to the final goal because the task becomes autonomous.

Rule 2 --- Active learning environment that allow try and error strategy need be supplied

Motor skill learning is mainly achieved through observation, audio learning and involvement by hand and muscles. It is typically a repeated loop among mimic, make error, modify and improve etc. Give error information and hint about what is correct is two helpful points in haptic training, which not only have direct effect on user’s muscle, but also enable an intuitive and interesting education experience on user’s brain.

It may be possible to develop haptic training strategies...
that force the subjects’ active participation and attention and thus promote learning. Within the above environment, error information must be supplied to gives cues of what is wrong and reward need be given to encourage what is right.

Rule 3—Approach for enhancing kinesthetic memory is important

Kinesthetic memory is the ability to remember limb position, velocity, etc. It is this ability to remember motor patterns that is exploited by haptic training. Scientific training procedure and repetitive loop among different training modes during learning is required to reinforce the memory on difference between right and wrong.

Rule 4—Quality of both afferent perceptual information and efferent control signal are both important

In order to improve quality of sensory feedback, haptic information should be combined with other sensory modalities such as visual and audio feedback.

Haptic training is different from visual training in the sense that training occurs in body centered, or motor, coordinates as opposed to visuo-spatial coordinates. Therefore, quality of both perceptual information and output energy are important for motor skill learning.

Concerning about the quality of the efferent haptic control signal, fidelity and stability of haptic device and high performance haptic rendering algorithm are two critical components in the system.

C. Multi-phase machine-mediated training method

Based on the four rules in previous section, a hierarchical training model using hybrid guidance and control method is proposed in Chinese handwriting training as figure 2 shows. A multi-phase, multi-mode, multi-modal feedback training system need to be established for satisfying the machine-mediated training purpose.

Active guidance is adopted for the cognitive stage. Active physical guidance by means of record and replay strategies is effective for strengthening perceptual trace or recognition memory.

Passive assistance strategy or passive intervention via virtual fixtures is adopted for the associate stage.

It has been demonstrated that both passive and active assistance during training of a dynamic targeting task serve to improve human performance of the task in an unassisted mode [11]. The two learning stages are systematically combined and are repeated in a loop to enforce trainee’s kinesthetic memory on handwriting effect.

III. HAPTIC-ENABLED TRAINING PLATFORM

A. Configuration of the platform

Experiment platform is constructed using Phantom desktop®, and Chinese handwriting simulation software is developed using computer with Intel P4 2.4G and DDR 512M memory. Figure 3 gives the scenario of handwriting operation.
In fig. 4, strokes-sequence based rendering architecture is proposed to enable haptic Chinese handwriting training [12]. Wrist of the operator is required to be fixed on the desk and pen-grasp is required during writing process.

B. Haptic-visual multi-mode training method

As figure 5 shows, specified Chinese characters “北京航空航天大学” are selected to validate system performance. Trajectory of reference template is displayed in blue color. Current active character is displayed in yellow color and actual trajectory result of the virtual pen is displayed in light green color. Error of actual trajectory and referenced trajectory can be seen clearly. In addition, a red ellipse is drawn at beginning control point of current active stroke to give a hint for the operator.

Three training modes are introduced to study relationship among the function of force feedback, graphical feedback and memory involvement. In facsimile mode as figure 5 shows, force feedback and graphical feedback are collocated. In transcribe mode as figure 6 shows, force feedback and graphical feedback are non-collocated while memory did not involve in the writing process. In reciting mode as figure 7 shows, standard character templates are hidden from the graphical scene. The operator writes the specified character at given position at given size according to the trajectory of the character stored in his/her memory.

C. Trial-evaluation-feedback training procedure

Before formal trial, participants are allowed to write a specified character for a few times to get familiar with the system. When formal trials begin, new characters different from the learning character are loaded into the system. Participants are required to write each character for several times. Score (SDP) and time used for each character and all strokes are recorded in real-time, and average score will be computed. Under each mode, learning process can be divided into three phases: before force guide phase (BP), force guide phase (FP), post force guide phase (PP).

For each trainee, the training/writing procedure is defined as follows:

1. Informal trial phase:
   a) Initialize the training mode to be facsimile mode
   b) Operator writes character “北” for one time to get familiar with the haptic system

2. Formal trial phase under facsimile mode:
   a) Formal trial begin and set the training mode to be facsimile mode
   b) BP: Operator writes character “航” without force feedback for five times and the system records the score and time
   c) FP: Operator writes character “航” with force feedback for five times and the system records the score and time
   d) PP: Operator writes character “航” without force feedback for five times and the system records the score and time

3. Formal trial phase under transcribe mode:
   a) Set the training mode to be transcribe mode
   b) BP: Operator writes character “航” without force feedback for five times and the system records the score and time
   c) FP: Operator writes character “航” with force feedback for five times and the system records the score and time
   d) PP: Operator writes character “航” without force feedback for five times and the system records the score and time
4. Test is finished and the evaluation data is saved into data file on the disk.

IV. EXPERIMENT

A. Experiment goal and parameters

The goal of the experiment is to validate the effect of haptic training during motor skill learning. Training effect based on comparison of different user, different training mode, and different control method will be analyzed.

B. Result

Specified character “航” can be used as an effective benchmark character because both basic and compound strokes are included in the character. Force curve and graphical scene under different parameters selection can be compared to observe stability and training effect.

There is one compound stroke “艹”的 stroke, where 6 feature points exist in this stroke. Figure 9 gives force signal of writing process on the compound stroke. Ambiguity of collision detection can be avoided by using active stroke method. Stability can be ensured when each feature point is passed.

Figure 10 gives results of writing without haptic feedback and Figure 11 gives result of writing with haptic feedback. Both results are conducted under facsimile mode. It can be seen clearly that the trajectory error is reduced with help of force feedback. The same results can be observed on other Chinese characters.

![Fig. 9 Force signal of compound stroke](image)

**Fig. 9 Force signal of compound stroke**

![Fig. 10 Result without haptic feedback](image)

![Fig. 11 Result with haptic feedback](image)

Figure 12 and 13 give mean value and distribution of score for all the participants under facsimile mode and transcribe mode. Figure 14 and 15 give mean value and distribution of time for all the participants under facsimile mode and transcribe mode. The average score in FP is always higher than that in BP and PP. The average consuming time in FP is always lower than that in BP and PP. Furthermore, there is no apparent difference between the writing precision and efficiency in BP and those in PP.

![Fig. 12 Score under facsimile mode](image)

**Fig. 12 Score under facsimile mode**

![Fig. 13 Score under transcribe mode](image)

**Fig. 13 Score under transcribe mode**

![Fig. 14 Time under facsimile mode](image)

**Fig. 14 Time under facsimile mode**

![Fig. 15 Time under transcribe mode](image)

**Fig. 15 Time under transcribe mode**

Figure 16 (a-b) gives average score of native and foreign participants under two training modes and comparison between with force feedback or not. It can be found that effect of force feedback is apparent for either native person or foreigners.

In native person test, score with force feedback (FF) is 20.4% higher than that without force feedback (NFF) under facsimile mode. Score with force feedback is 31.1% higher than that without force feedback under transcribe mode. In foreign person test, score with force feedback is 37.2% higher than that without force feedback under facsimile mode. Score with force feedback is 34.0% higher than that without force feedback under transcribe mode.

![Fig. 16 (a) Average score of native participants](image)

**Fig. 16 (a) Average score of native participants**

![Fig. 16 (b) Average score of foreign participants](image)

**Fig. 16 (b) Average score of foreign participants**

C. Discussion

It can be concluded that SDP fidelity criteria is suitable for evaluate trajectory error between human operator’s hand and virtual pen’s tip. It can be used as quantitative criteria for evaluating training effect and as a benchmark to improve and optimize rendering algorithm.

Writing efficiency and accuracy under force feedback is
better than without force feedback. For novice trainee, the effect of using haptic training is especially apparent. However, the effect is not apparent as we expected. It is assumed that small-scale repetition is not enough for cultivating kinesthetic memory.

It seems that using different training strategy at different learning stages is helpful for users to get familiar with the task easily. Active guidance in the cognitive stage is intuitive for trainee to quickly understand what need is for the task goal. Assistant and passive guidance allow the trainee to actively try and to refine along his own learning action, thus result in interesting and deeply remembered motor pattern.

Quality of both perceptual information and output energy is important for maintaining effective motor skill learning. Not only stability but fidelity of force rendering is required to improve training effect.

V. CONCLUSION

Contribution of this paper is to propose an effective method to training complex motor skill. It has been realized in three steps: establish machine-mediated training rules enlightened by human learning criteria, develop multiple sensory feedback training platform implement the proposed rules, carry out human subject experiment to validate the proposed rules.

Motor skill presentation based on stroke sequence is proposed and four rules of haptic training are proposed: focus on first two learning stages, supply try and error leaning environment, memory reinforcing of hand and wrist muscle, and to enable coordination between hand and eye.

Prototype of haptic simulation system is established and training method combined haptic and visual feedback is designed to study learning mechanism of motor skill.

Performances of all the trainees among different training mode and different sensory feedback modal are recorded and analyzed. The result shows that writing efficiency and accuracy under force feedback is better than without force feedback.

Our future work will investigate how to evaluate training effect of the system quantitatively. More human subjects will be invited to use the system and their writing information will be recorded and analyzed.

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