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# An adaptive haptic guidance software module for I-TOUCH: example through a handwriting teaching simulation and a 3D maze.

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***Abstract –*** *This paper introduces a new method for virtual reality teaching and its implementation into the I-TOUCH framework. From a thorough analysis of previous works dealing with virtual training, we developed a four steps method to be used for teaching and training. The I-TOUCH framework has been designed in order to quickly prototype computer haptic research and subsequently generate actual industry interactive simulations. Adding a progressively adapting guidance software module, the software can also be used to teach and train people on skill manipulation, where the use of haptic feedback increases learning. Thus, we decided to conceive a replay mode where four different haptic displays were possible: from total guidance, through more or less haptic correction of the user gesture, to a simple visual mode, where the ideal motion is visually displayed.*

***Keywords –*** *mixed reality, adaptive haptic guidance, record-and-replay, virtual teaching, training.*

## I. INTRODUCTION

Generally, real training for various tasks is either expensive or rather long. Numerous studies have been made in order to determine the advantages virtual training could provide. Certainly, in many cases, the use of virtual simulator makes it less expensive and less dangerous than classical methods. Over the past years, several researches have been made on this topic and it has been revealed that visual modality has an utmost importance in information transfer. Moreover it has also been pointed out that adding haptic modality to visual cues, increases the efficiency when some complex skill need to be taught. Hence, virtual simulators, where haptic and visual cues are provided, seems to be a efficient means to teach several tasks. Nevertheless, one of the counterweights in those techniques is a possible occurrence of dependence between the student and the teacher. Consequently, we took into account those results to strengthen our proposed method.

When learning how to ride a bicycle, 4 steps are more or less necessary. First, someone has to show how to do it (the leading part). Then on a 4 wheels bike (with the 2 extra small ones on the side), someone help the pupil by pushing him in the back (to follow the good path). In the next step, only the extra wheels are remaining (to correct the movement). Finally, the last stage is the free ride. Therefore, we designed our approach similarly to this 4 stages paradigm. Going through those different steps, help is gradually decreased, and hence the dependence is slowly disappearing (likewise when stopping to smoke), avoiding the possible drawbacks. Visual cues are also provided since the influence of this modality represents a primary requirement for teaching. Nonetheless, as well as for the possible haptic dependency, this issue can arise for visual part and thus a digressively visual help should be provided.

The I-TOUCH framework has been designed to provide an open architecture and powerful tools for benchmarking robustness of subsequent algorithms, dealing, in the meantime, with issues of high refreshing rates and physically-based simulations requirements. Adding a “record and progressive teaching replay” software module, it becomes a powerful tool for creating training applications. Thus, we tested our approach of teaching through two examples: a simple handwriting simulator and a more complex 3D scenario where users had to move and find a 3D maze exit.

## II. RELATED WORK

Various research has been done for determining the efficiency of virtual training compared to classical real coaching. As exposed in those studies, there are some tasks more easily taught through haptics than verbally. Particularly handwriting, where essential motor skill through kinesthetics must be provided. Through those studies, one can notice that haptic cues are not enough, since visual information provide better understanding of the task to be done. Moreover, simple guidance is not efficient due to increasing dependence of the pupil on the teacher for performing the task and therefore, adaptive teaching could prove more efficient. Finally, the different results obtained showed than after short periods benefits of virtual training disappeared.

### *A. Virtual teaching/training*

In [14], Gillepsie *et al.* describe their idea of a virtual teacher when haptic modality is present. Cheaper and safer than in the real-world environment, their hypothesis is that in virtual environment, learning can be faster and improved. The

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difference between a virtual teacher and a virtual fixture, which help users by guiding them, is that virtual teacher paradigm is only used during training periods. Their goal is to leave the student performing on its own as soon as possible. This is consistent with the problem related in [12] that pupil can become dependent on the teacher and therefore their performance increases poorly. After testing on an "crane-moving" task experiment, results were inconclusive to their hypothesis on the effectiveness of the virtual teacher.

There are different strategies of skill training: adaptive training, to avoid a possible dependence from the student on the teacher, guidance, where users are helped to avoid making errors even if people learn from mistakes they have made, as notified in [12], or leading. Using their WYSIWYF system emphasized with visual/haptic, [2] made registration combined to a "record-and-replay" strategy and tried different training methods, namely using combination of visual cues and different playback (force, motion, both) to determine the essential data providing the better transfer of skill. Results of this work were inconsistent. Actually the task was too easy and force playback was disturbing and providing an unnatural feeling. But, as they pointed out, they did not find the good requested force to display.

In [1], authors study skill mapping from human to human via a visual/haptic system (since training is a kind of skill mapping), and point out that motor skills is better transferred through haptic. Various researches have been made in order to expose the benefits of teaching tasks through haptic method, as exposed in [10] where better results were obtained on experiments when using augmented feedback than when using classical coaching or extra practice of the tasks. Moreover, they pointed out that only the relevant part of information required for skill transfer should be emphasized to improve the efficiency of training. As reminded in the conclusion of [14] and [2] and pointed out in [1] and [10] a too much easy task to perform is not enough to prove or highlight such a hypothesis.

Haptic training seems ideal for teaching complex motor skill, but since visual modality has a paramount importance in information transfer, visual cues have to be added. [12] points out that learning can be split up in 3 stages: cognitive (where users get the what to do), associative (how to do) and the autonomous (when they are self-sufficient in performing the task). Hence, teaching should be made in the first two stages. Finally the authors of [12] made an experiment using a PD (proportional-plus-derivative) haptic guidance and visual cues, where participants were taught a 10 second complex 3D-motion. Their analysis of the results revealed that shape and position are more precisely understood through visual cues but timing accuracy depends on haptic, and therefore haptic training should be coupled with visual training to improve the teaching task, as noticed [5].

The paper [5] reports a discussion about how adapting usual help systems to efficiently help users. First they notice that help systems, which are different from training ones, should not overload the user's interface. Moreover, in general, people do not take advantage of help systems provided. Hence, they tried to gather their analysis results to design a better system. They noticed that with two kinds of interaction, namely demonstration and guiding, haptic guidance should provide the ideal mean for teaching and helping, avoiding the confrontation between leading and helping. It is the better assistance they could find.

The study of [3] tries to establish a method of virtual-reality-mediated motion/force teaching, since particularly, specific aspects to be taught can be emphasized and it makes easier to teach some instructions. In haptic guidance, motion can be transferred but not forces. Hence, they developed a mechanism to do so. The conclusion was that a student gets the teacher's action clearly (precisely) but did not reproduce it is perfectly (inaccurate).

We intended to test the benefits of our idea through two different scenarios, namely an handwriting teaching simulation and a 3D maze. The latter was a simple experiment trying to highlight the difficulty in performing a task when no visual information is available, like in some maintenance work.

### *B. Handwriting systems, (with teaching or not)*

Some previous researches have been made on how to teach correct writing, through the use of haptic guidance. In [6], the authors have developed a system using a *record-and-replay* strategy to teach person how to write Japanese calligraphy, which is a peculiar form of writing. In [8], authors present a Haptic Interface (HI) coupled with a Reactive Robot (RR) technology to teach people how to write, here also, a japanese letters; a recognition system is used to analyze user motion in order to "understand" which characters one wants to write, and hence, the control system provides the proper force feedback, using a simple law control to restrict user's motion along a predefined trajectory. Nevertheless this paper mainly focuses on the recognition part to disguise restriction of usual tutor/robot-aided based on HI (haptic feedback but no guidance).

[9] introduces a new paradigm providing closest possible replication of expert's skill. "Haptic attribute", a unique haptic force profile for every kind of task, is then presented. Moreover a demonstration of its efficiency is proved, by comparing this method, with classical training and haptic assisted one, through a training handwriting system. Thus, in this demonstrator, force profile is used as the information necessary for the control, a "force feedback control". The authors imply that if nature of forces generated by teacher and pupil are the same, then their trajectories will be similar. The results obtained concurred their hypothesis, namely a record-and-replay training with force information is better than one with only position control. The authors of [7] present an interactive haptic system, where, holding a force feedback device, artists feel like holding real brush and the interaction contact is as if for real. Emphasizes have been made on reality of the brush and the interaction with the paper. No haptic guidance has been used and only the force feedback is provided to users.

### C. Maintenance training

A similar approach of virtual training for maintenance has been used in both [11] and [13]. Actually they designed virtual simulation where users were able to choose different modes of interaction with the simulation. To deal with the increasing complexity of objects, traditional training method are no more sufficient. Therefore, virtual simulations are prone to become the primary mean of dealing with it. The authors of [11] proposed a four-different simulation modes to teach people on the project AITRAM. These modes were separated in presentation, guided, free and a discovery one. Then users were able to interact at different level with the virtual environment. In [13], only two modes were proposed, namely a free one and a guided one. In the same spirit, we propose to go further in creating simulation where users could haptically interact with the simulation and adding the possibility to choose different levels of guided tour, making it progressive.

We finally designed our solution as a software module which have had been incorporated into the framework I-TOUCH.

### D. The I-TOUCH framework

This I-Touch framework [4] has been developed recently to help researchers to quickly create simulation to validate their work. The fact that current haptic frameworks are often device oriented or use a specific simulation algorithm which can be quickly become limiting, if researchers are willing to test different scenarios. Moreover, the tedious tasks of creating a special application, where multi modal rendering is necessary, can be quickly very time consuming. The I-Touch framework aims at reducing the delay between the thought of a haptic principle, and its very implementation with tests. While the I-Touch framework is mainly oriented toward real time rigid body dynamics, it features a very modular architecture, in order to be able to replace components easily. Moreover, each component can be configured through a set of simple XML files. These XML files are easily created and modified as new components are added to the framework. The fact that the framework is not dedicated to only one haptic device allows changing the configuration for the device chosen, and then running the same simulation without changing one line of code. Direct access to the device forces is provided, if needed by the application. This tends toward a 'plug and play' architecture, where every part of the framework is modifiable, configurable, and replaceable.

We decided to add a component to record and then replay a recorded path, in 2D or 3D. This component will not requires rigid body dynamics, however it will benefit from the 3D rendering (the sound part is not of utmost importance), scene management and of course of force feedback device management. It will plug in the place of the current simulation manager. Only one file needed to be replaced in the framework, the one that contains actual algorithms, the remaining parts are configured through XML. The implementation of this solution proved itself very easy.

## III. PROGRESSIVE REPLAYING SYSTEM

As highlighted in the previous work analysis, it is not sufficient to provide users neither with a full guidance neither nor a simple training system. Our idea was to provide a *record and progressive-replay* strategy system, where the initial step is to record the ideal motion (in 2D or 3D) performed by the teacher. Then the following stages are to provide users help from total guidance to partial correction.

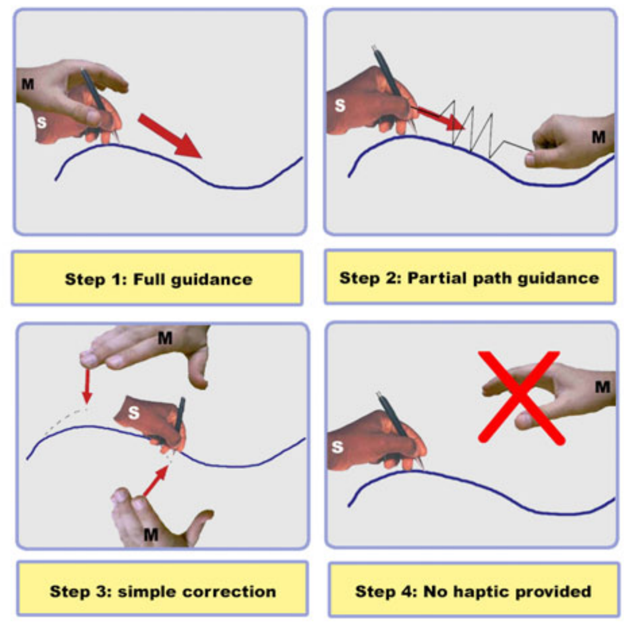


Fig. 1. The three adaptive steps for teaching, between a master (M) and a student (S). On step 1, S is fully driven by the master (full mode). Then S is pulled by M on the path, on step 2. For the final teaching stage, if S is lost and is no longer on the track, M help him to come back on the path. Eventually, S is free to move and no haptic help from the teacher is provided.

### A. Recording the ideal motion

For our work, we use the well known PHANToM[1] device and when performing the motion required, points are recorded. Therefore it is obvious that recording a task in 2D or in 3D is similar and both 2D and 3D motion can be saved.

### B. Guidance

The guidance provided is adapted to user's performance. Hence, different levels of guidance are proposed:

#### B.1 Full teaching

User's hand is inactive and just holding the handle of the haptic device, users are shown what is asked to be performed, step 1 on figure 1.

[1] www.sensable.org

B.2 Partial path guidance

Here, we let the user take control of the haptic device but when lost in the process, kinesthetic forces are applied onto the user's probe to get back in the direction of the track, step 2 on figure 1.

B.3 Simple correction

Finally, in the last mode, forces are applied to the haptic device when the user makes errors, but contrary to the previous mode, no indication on the track direction to follow is provided. Only a force pushing him to come back on the track is sent, step 3 on figure 1. Thus, users are able to move backward and forward as long as they stay on the track, what is not possible in the previous mode.

### C. Guidance implementation within I-TOUCH

The implementation of our concept consisted in determining the appropriate forces to render through the haptic device to users. In addition to the ones due to 3D environmental interaction, we calculated extra forces corresponding to the haptic virtual help. The first step consists in recording the teacher path, labeled $Path$, and a set of key points $X$ is determined. Then when using the virtual help, a mode has to be selected. The full guidance, partial, and simple correction modes are designated $full$, $partial$ and $simple$. The loop is incremented relative to the haptic step. $X_i$ and $X_c$ are respectively the ideal position at the $i$-th step and the current one, i.e. the one of the user. $CP_{\text{path}}$ is the function to determine the closest point, one of the recorded ones $X$, to the current one, while $CP$ represents the function finding the closest point, belonging to the recorded path (i.e. not necessary a recorded point but one interpolated between the key ones), to the current one. $k$ and $k'$ are respectively the proportional and damping correctors. The damping corrector is used to smooth the replayed trajectory. Eventually, those forces $F_i$ are added to the haptic forces $F_{\text{simu}}$ coming from the interaction with the virtual scene (as when touching an object, or feeling friction...). Hence, users feel haptic feedback from the interaction with the scene and from the haptic virtual helper.Hence, we used the three following methods:

**Algorithm 1** Force determination

**for** each haptic step $i$ **do**
  **if** mode == full **then**
    $F_i = k \times (X_i - X_c) + k' \times F_{i-1}$
  **else if** mode == partial **then**
    $X_{\text{path}} = CP_{\text{path}}(\text{Path}, X_c)$
    $F_i = k \times (X_{\text{path}} - X_c)$
  **else if** mode == simple **then**
    $X_{\text{path}} = CP(\text{Path}, X_c)$
    $F_i = k \times (X_{\text{path}} - X_c)$
  **end if**
  Apply $F_{\text{simu}} + F_i$
**end for**

The difference between the functions $CP_{path}$ and $CP$ is that the former is forcing users to go from each haptic loop to the next key point defining the recorded path, while the latter only restrains him on the path.

### D. Visually displaying the recorded path

In 2D or 3D, the recorded path is visually displayed. As a matter of fact, the importance of visual cues has been shown and therefore it is beneficial to have this visualization. Nevertheless we made it possible to switch off the visual display in order to properly evaluate the haptic cues benefits.

## IV. EXPERIMENTING OUR APPROACH

To experiment the efficiency of such an approach, we decided to test it through two different simulations. The first one was a simple handwriting system where, after recording some letters(ideograms), users were using our simulator to learn how to write it correctly (the same way children do when they are in small classes). The second simulation was based on the assumption that this kind of technique could also be used for maintenance training.

For both simulation, our apparatus was composed of a PHANToM Omni (Sensable technology) linked to the I-TOUCH framework on a classical personal computer (Pentium 4, 3.2 GHz, 1Go Ram, Radeon X800XT). The procedures of both experiments consisted in the realization of the same tasks for 3 kind of training: *group 1* only training by themselves, *group 2* using only the full teaching guidance (as if a teacher was showing it several times) and *group 3* using our method of learning and training, after being told how does the three steps method works.

### A. Handwriting teaching system

To evaluate the efficiency of the proposed progressive guidance, we decided to compare how users retain how to write a Japanese ideogram. As a matter of fact, compared to some other language, to write a kanji, like 'uma', see figure 2, there is an order to follow to properly write it, see figure 3 and therefore the haptic guidance can more than helpful to remember it. Six people took part in the test and were divided into three groups. Two women and four men, all aged between 24 to 28, none having had previous knowledge of Japanese calligraphy, took part of the experiment.

### B. 3D blind-maze path

As quoted in [12], in situations where visual information is unreliable or unavailable, haptic may be the only way to improve the training. Actually, in maintenance, it is often the case that the place where the reparations need to be made is not visually reachable. Therefore operators have either to use schematics of the object(s) or blindly and exhaustively search manually how to manage it, see figure 4. If the operation needs to be repeated several times, training could become necessary and useful. Hence, one solution is to train them on a real duplicate or on a virtual one. In this latter case, instead of letting

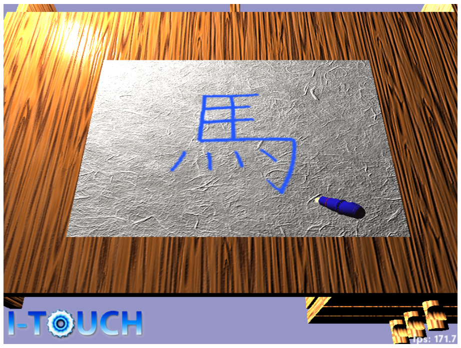


Fig. 2. How to write 'horse'(uma) as a Japanese ideogram, for which the order on how to write it, is important. Therefore haptic guidance is more than helpful to teach the ideal solution.

Fig. 3. The ten steps on how to write the Japanese kanji 'uma'.

them find their way alone, what requires time and is not necessary precise, haptic guidance is beneficial.

In this second experiment, we developed a 3D maze, see figure 5, and subjects were asked to remember a specific path through it. The main point being that no visual display of the labyrinth was available and only force feedbacks were returned to inform users of their moves. The interest in this experiment was first to establish if missing visual cues could be overcome through longer haptic training, and secondly if that kind of approach could be applied for maintenance simulators scenarios where no visual display is available. Height persons, 2 females and 6 males, only one having previous experience with haptic simulation, all aged between 24 to 50,, took part in this experiment. As in the previous test, people were separated into the three kinds of training groups. To evaluate the performance, we decided to check time taken to resolve the maze.

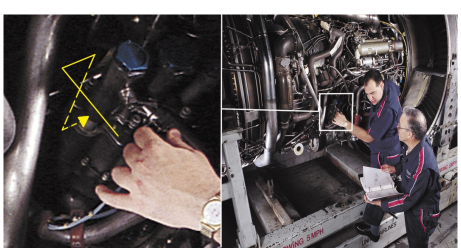

Fig. 4. Maintenance without a visual information feedback. Either schematics or handy exhaustive searching are used to find the way.

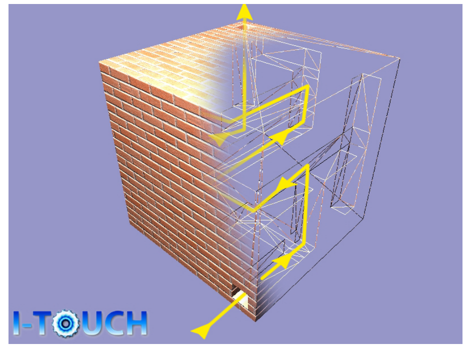


Fig. 5. The maze simulation. Users were haptically shown a 3D path to follow without visual feedback. This experiment was designed to point out how people deal to find their way when not having visual return, as in some maintenance scenario.

## V. DISCUSSION AND FUTURE WORK

### *A. Results*

The results obtained for each experiment are :

- for the handwriting teaching system:
  The Japanese ideogram test interest relies in the writing order to be followed. Hence, haptic teaching benefit was to give that extra information which would not have been assimilated so easily if relying only on visually and/or speech supports. The 2 last groups reported that the help provided was useful but no significant difference was noticeable between the two. Even the first group understood the instructions when the teacher told them orally how to do it. This ideogram was not so hard to remember. Nonetheless, we can hope to show that on a more difficult kanji or drawing, the last method is more powerful and in the perspective to imagine a virtual teacher, not having the ability to clearly give the information orally, a haptic guidance approach is necessary.
- for the 3D maze test:
  This second experiment was more difficult for users. As a matter of fact, not having a visual display is a primordial handicap. Figures 6 and 7 synthesize the data recorded to evaluate our method. The first, second and third groups of columns respectively represent the results obtained for the simple, medium and hard maze. For each of these groups, the left, middle and right columns are the average time taken for the groups 1, 2 and 3. Four major results:
  1. time taken for training is coherent with the fact that people from group 2 are forced to follow the ideal motion, while for the other groups, they can take their time to explore.
  2. coherently, the less complex the task is, the less difference there is between the groups time of resolution.
  3. it appears that the full guidance mode resolution time, which does not allow the possibility for people to explore by themselves, is the least efficient. We notice

that this is consistent with the fact that people learn from their errors.

4. Finally, solving time for the last mode is better than for the other modes. If we take into account the results from the time spent in training, it appears that people spent less time in training for better results, in that same group. Moreover, we notice that the more complex the maze is, the better the third group results are, compared to those of the other groups. They learned the task faster and easier.

People can notice that for the group 1, time spent in resolving the medium mazes are on average longer than for the more difficult. This can be explained by the fact that we tested fewer hard mazes and moreover the difference between hard and medium difficulty was not that significant.

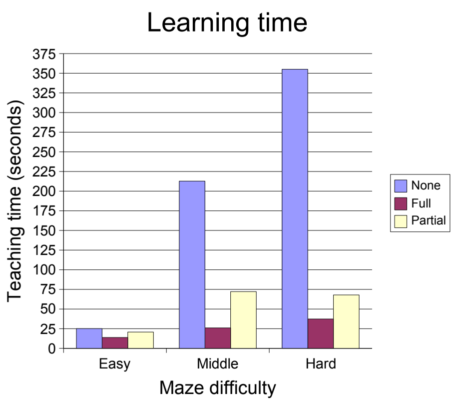


Fig. 6. Teaching time spent for the 3 different groups for each difficulty of the mazes.


Fig. 7. Resolution time spent to find the exit in the different mazes for the 3 groups.

## B. *Future work*

The future steps of our development includes:

- improvement of our method by making it possible to change the level of guidance automatically by evaluating the level/performance of the user during the process.
- addition of new visual augmented features to enhance the help effectiveness.
- exploration of long time effects.

## CONCLUSION

In this paper, we presented a progressive guiding system designed as a software module for the framework I-TOUCH. Through a handwriting teaching simulator and a 3D maze one, we tested our haptic enhanced paradigm for teaching and training skill. As expressed in some former works, people learn from their mistakes and training on virtual method can not, for the moment, fully prepare to deal with real actual issues. Nevertheless, benefits of combined visual and haptic simulators are numerous and by adding our progressive approach, we think we avoided one of the principal drawback of such methods, namely the dependence to the teacher. More advanced tests would be necessary to concur with such a hypothesis .


[1] Yokokohji Y., Hollis R., Kanade T., Henmi K., and Yoshikawa T. “Toward machine mediated training of motor skills -skill transfer from human to human via virtual environment,” in *5th IEEE International Workshop on Robot and Human Communication*, pp. 3237, Nov. 1996.

[2] Hollis R., Yokokohji Y., and Kanade T., “What you can see is what you can feel,” in In *Proc. IEEE Virtual Reality Annual International Symposium (VRAIS96)*, pp. 46 53, 1996.

[3] Kikuuwe R. and Yoshikawa T., “Haptic display device with fingertip presser for motion/force teaching to human,” in *Proc. of the 2001 IEEE International Conference on Robotics and Automation*, 2001.

[4] Pocheville A. and Kheddar A., “I-TOUCH: A framework for computer haptics,” in *International Conference on Intelligent Robots and Systems, Workshop on Touch and Haptics*, Sendai, Japan, Sept.28-Oct.2, 2004.

[5] Szilas N. and Ramstein C., “Haptic assistance for graphical user interfaces: Theoretical foundations”, 1996.

[6] Henmi K. and Yoshikawa T., “Virtual lesson and its application to virtual calligraphy system,” in *Proc. of IEEE International conference on robotics and automaton*, 1998.

[7] Yeh J., Lien T., and O. Ming., “On the effects of haptic display in brush and ink simulation for chinese painting and calligraphy,” in *Proc. of the 10 th Pacific Conference on Computer Graphics and Applications (PG02)*, 2002.

[8] Solis J., Avizzano C.A., and Bergamasco M., “Teaching to write japanese characters using a haptic interface,” in *Proc. of the 10th Symposium On Haptic Interfaces For Virtual Envir. and Teleoperator Systs.*, 2002.

[9] Srimathveeravalli G. and Thenkurussi K., “Motor skill training assistance using haptic attributes,” *WorldHaptics 2005*, 2005.

[10] Todorov E, Shadmehr R, and Bizzi E., “Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task,” *Journal of Motor Behavior*, vol.29, pp. 147158, 1997.

[11] Bluemel E., Hintze A., Stuering S., Schumann M., and Schulz T. “Virtual environments for the training of maintenance and service tasks,” in *Proc. of the 2003 Winter Simulation Conference*, 2003.

[12] Feygin D., Keehner M., and Tendick F., “Haptic guidance: Experimental evaluation of a haptic training method for a perceptual motor skill,” in *Proc. 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pp. 4047, 2002.

[13] Corvaglia D., “ Virtual training for manufacturing and maintenance based on web3d technologies,” in *Proc. of LET-Web3D 2004: 1st International Workshop on Web3D Technologies in Learning, Education and Training* , pp. 2833, 2004.

[14] Gillespie B., OModhrain S., Tang P., Pham C., and D. Zaretsky. “The virtual teacher,” in *Proc. of the ASME IMECE*, vol.64, pp. 171 174, 1998.