Development of Maintenance Training System by Using Haptic Guidance

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Abstract In order to do a maintenance task, a maintenance operator should learn the basic skills of the maintenance task such as assembly and disassembly (A/D). However, the key of the learning process is to learn the A/D task intuitively and naturally. Haptic guidance promises to give effectiveness and benefit qualitatively since a person can be trained to do the optimal task based on information that comes from an expert, database, or intelligent algorithms. By applying haptic guidance, a maintenance training process can be made more intuitive and natural in a virtual environment. This paper describes the development of a maintenance training system by using haptic guidance.

Keywords : A/D Task, Haptic guidance, Maintenance, Virtual Reality

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1. Introduction

A growing number of advancements in haptic technologies in the field of virtual reality (VR) are contributing to the development of haptic applications in such diverse fields as medical diagnosis and surgical simulation, games, etc. Users can feel the tangibility of the virtual objects by applying haptic rendering algorithm in the virtual environment. The force-feedback mechanism which is used as the basis of haptic rendering algorithm is not only used as the means to feel the virtual object, but also as a guide to generate forces for doing some task. In the field of medical haptics, Okamura *et al* have successfully developed a haptic guidance application for microsurgical purposes [1]. Their mechanism guides users along a path by making the movements parallel to the path easier than in the perpendicular direction. Teo *et al* have developed a 6-dof haptic interface for Chinese handwriting teaching purposes [2]. In the manufacturing field, Wang *et al* have made a training application for arc welding purposes. The haptic welding application gives training for three basic welding skills: maintaining proper arc length, electrode angles, and the traverse speed [3]. Their haptic guidance was realized with proportional-plus-derivative (PD) feedback control of error between the current and ideal trajectory. The effectiveness of haptic guidance in applications might quantitatively depend on the specific application. However, haptic guidance promises to give effectiveness and benefit qualitatively since the trained persons could be trained to do the optimal task based on information that comes from an expert, database, or intelligent algorithms.

We realized that haptic guidance could also be applied for maintenance training system. In order to do a maintenance task, a maintenance operator should learn the basic skills of maintenance task such as assembly and disassembly (A/D). Operators can learn from the maintenance experts or by reading the maintenance guidance books about how to do A/D task. However, the key of learning process is to learn intuitively and naturally the A/D task. The haptic guidance application for maintenance task training was built as the solution for the previously mentioned problem. By applying haptic guidance, maintenance training process can be made with more intuitive and natural ways. This paper describes the development of a maintenance training application by using haptic guidance. The paper covers the explanation about overview of the system, haptic guidance method, user-studies on the system, and conclusion.

2. Overview of the System

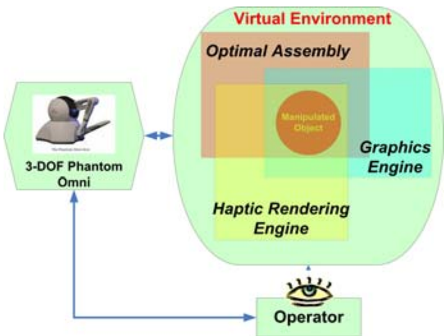


Figure 1. The components of the system

Virtual objects to be manipulated were made by using CAD software, and then the part files were converted to object files that could be read by the graphics engine. This maintenance training system uses CHAI3D API (Application Programming Interface) [4] for the graphics and haptic rendering engines. The GUI (Graphical User Interface) was designed to interface between the users (operators) and the virtual environment (VE). Users can manipulate the objects through the provided window that shows the VE. Users interact with the virtual environment using a 3-dof haptic device, specifically the Phantom OmniTM made by SenseableTM. This device can provide six inputs (Force, Torque) and three outputs (Force).

An operator can be guided by a haptic guidance algorithm through a prescribed path in the VE. The prescribed path is represented as a solid object in the shape of the path with boundaries on either side of the path. The operator is required to keep the movements of the parts always inside the path boundaries to avoid collision with the obstacles. When the operator begins to move away from the path boundary, a haptic guidance algorithm generates haptic forces to oppose the operator' s deviation from the collision free optimal path . The haptic guidance exists in the form of haptic reaction force when the collisions occur between pointer and path boundary. This scheme aims to train the maintenance operator through haptic guidance to move the parts along an optimal path. The determination of optimal path for A/D task is covered in a separate paper [5].

3. Haptic Guidance Algorithm

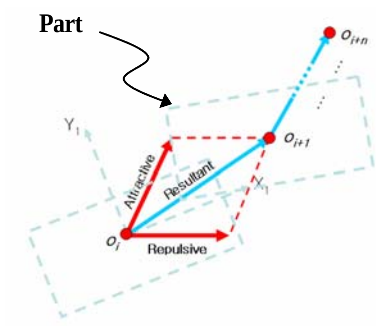


Figure 2. Path generations.

The haptic guidance algorithm to generate haptic forces is based on potential field method [6]. An operator should move the parts from their initial positions to final positions with respect to the assembly sequence of parts. The repulsive and attractive forces are combined to create the path that avoids the obstacles and brings a part to the final position point (figure 2). The repulsive and attractive forces are applied as follows;

if $\rho(o_i(q)) \le \rho_0$:

$$F_{rep,i}(q) = -\eta_i \left(\frac{1}{\rho(o_i(q))} - \frac{1}{\rho_0} \right) \frac{1}{\rho^2(o_i(q))} \nabla\rho(o_i(q)) \quad (1)$$

if $\rho(o_i(q)) > \rho_0$:

$$F_{rep,i}(q) = 0 \quad (2)$$

if $\|o_i(q) - o_i(q_f)\| \le d$:

$$F_{att,i}(q) = -\zeta_i (o_i(q) - o_i(q_f)) \quad (3)$$

if $\|o_i(q) - o_i(q_f)\| > d$:

$$F_{att,i}(q) = -d\zeta_i \frac{(o_i(q) - o_i(q_f))}{\left\|(o_i(q) - o_i(q_f))\right\|} \tag{4}$$

$$\vec{f} = \frac{F_{att} + F_{rep}}{\left\|F_{att} + F_{rep}\right\|} \cdot S \tag{5}$$

where :

q, q_f = configuration , final configuration of parts.

ρ_0 = repulsive force radius.

$o_i(q)$ = point on the workspace.

η_i , ζ = scale factor.

F_{rep}, F_{att} = repulsive, attractive force on i-th part.

i = index of i-th part.

d = distance from final position to current position

f = applied force to move the parts.

S = step between path points.

Normalization in equation (5) was applied to the vector since in many cases the magnitude of the vector is too big to be applied. The summation of the attractive and repulsive forces gives the direction of the part movement as a vector. In every path point (oi), the force will give a direction for the next path point toward the final position. Actually, this vector can be directly applied as a haptic guidance force for virtual maintenance system, but in our recent works we just utilized the resulted path to construct the guidance path as a solid object.

4. User-studies on the System

A user-study scheme has been prepared to evaluate the qualitative and quantitative effectiveness value of the maintenance training application with the haptic guidance. A number of participants were chosen as the operators of the maintenance process. The process of moving parts from initial to final position according to the suggested (optimal) path is the basic A/D task that should be performed by the participants as maintenance operators. The given assembly case was planar assembly where the objects were represented as 3d objects. The path planning was done for the planar movement. Below are the steps taken by the users during user studies.

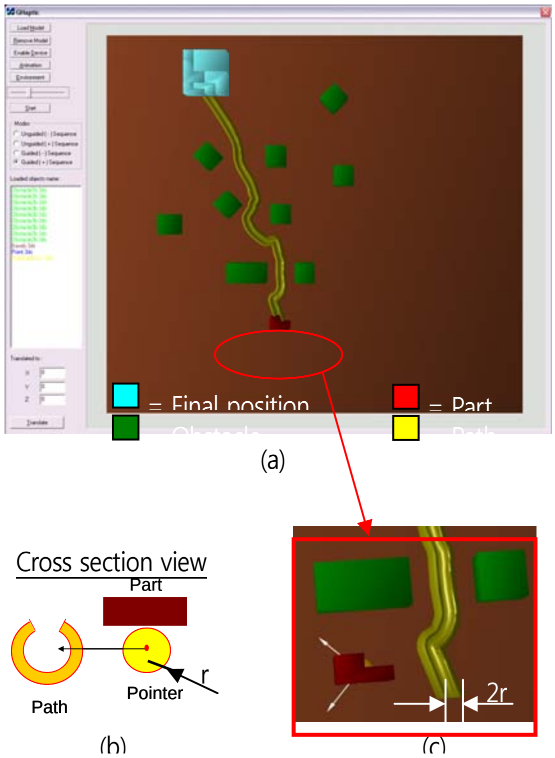
1. User clicks the environment button to load the environments objects.

2. User clicks the start button to activate the modes. Path and/or part objects will appear in the VE.

3. User clicks the enable haptic button to activate the haptic device.

4. User should pick up the part at the initial position by touching it. Then the part is automatically attached to the pointer.

5. When the user reaches the final position, the part



is automatically assembled through snapping in place.

Figure 3. The components of GUI and virtual environment

During the user studies, three modes were used to evaluate the performance of haptic guidance. First mode is unguided without suggested assembly sequence mode (*Unguided Sequence*). In this mode, the user only picks and moves the part to the final position without any information of guidance. The user should find the assembly path by himself and also avoid the collision with any objects in the VE. Only snap mechanism is available in this mode. The user should also determine the sequence of assembly by himself. They can pick the parts in an arbitrary sequence. The second mode is unguided with suggested assembly sequence mode (*Unguided + Sequence*). In this mode, the paths are not provided by the system, but the sequences of assembly are provided. The users just pick the parts based on the order of part's appearance in VE which represent the suggested assembly sequence. The third mode is guided with suggested assembly sequence mode (*Guided + Sequence*). In this mode, the optimal assembly path and assembly sequence are provided to the user. User can follow the path to assemble the part. The path in the form of solid body object is constructed by optimal assembly algorithm. The appearances order of path and parts in VE are following the suggested assembly sequence. The movement of the user is limited to the path boundary. Whenever the user' s movement begins to cross the path boundary, the user feels haptic reaction force between the pointer and the path boundaries. This scheme is considered as haptic guidance.

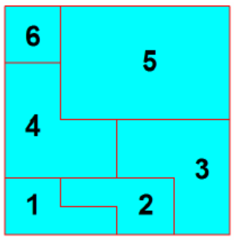


Figure 4. The assembled parts

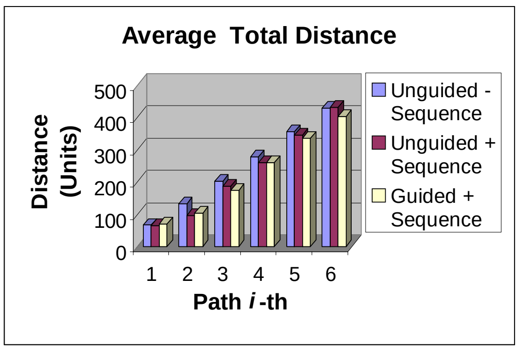
Eight participants consisting of 5 men and 3 women were involved as the user study subjects aging 23-29 years old. The given task is a planar assembly process of assembled objects which is shown in figure 4. The initial positions of the parts are set in different location on workspace. Each participant performed the assembly task in three modes. In order to get familiar with the VE and the scheme of assembly, the users were allowed to test the system two times at the beginning of the user study. Users were evaluated both qualitatively and quantitatively. The qualitative aspect was evaluated by asking the participants Yes/No questions after the participants had performed assembly simulation in our system. The quantitative aspect was taken by counting the needed time to finish the paths and actual total distance when user moved the part. Following are the list of questions and the participant' s answer.

1. For the overall, is the system helping you doing the assembly simulation (Y/N)?
2. Compared to non haptic, do you think the haptic guidance giving better perception to do the assembly task (Y/N)?
3. Compared to un-optimal path, do you think the optimal path give you less effort to do the assembly task (Y/N)?
4. Do you think the virtual assembly training is better than physical or conventional training (Y/N)?

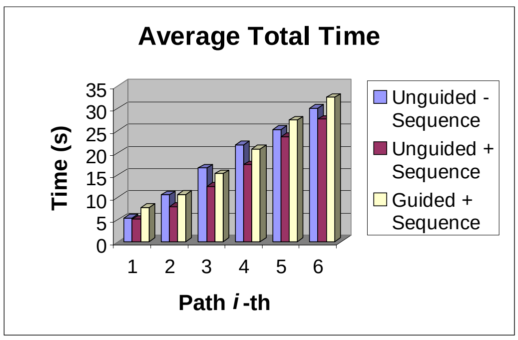
Table 1. Qualitative aspects

Participants	Answer of i^{th} questions			
	1	2	3	4
1^{st}	Y	Y	Y	N
2^{nd}	Y	Y	Y	Y
3^{th}	Y	N	N	Y
4^{th}	Y	Y	N	N
5^{th}	Y	Y	Y	Y
6^{th}	Y	Y	Y	N
7^{th}	Y	Y	Y	N
8^{th}	Y	Y	N	Y

In terms of total average distance per path and total required time per path, the result shows that the assembly task assisted by guidance and sequence is better than without guidance and sequence. The assembly tasks with suggested sequence are better than without suggested sequence, since two modes (with suggested sequence) give good average total distance and total time (figure 5.a and 5.b). The times



(a)



(b)

Figure 5. The quantitative Data

needed to finish the assembly task with suggested sequences mode are reduced compared to without sequence and without guidance mode (figure 5.b). The assembly tasks with guidance are also better than un-guidance mode even though there are some bad average total times in several points (figure 5.b). Guided and sequence mode has bad result only in three path (1th , 5th , 6th path), since one participant gave very bad result for this path that gave peak value in the data. It should be noted that the space perception ability and learning rate of participants vary from one to another that can give peak values in the user study data. Mainly, the lack of space perception came from the participant' s natural ability and our system itself since we used 3-dof haptic device in 3d space. Some

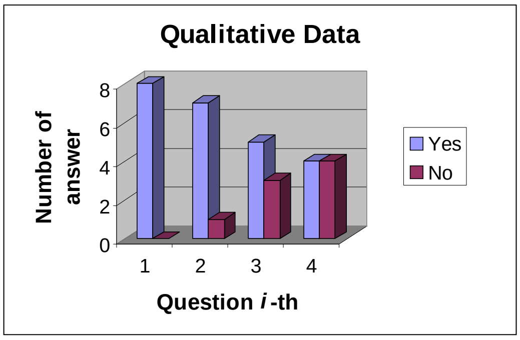


Figure 6. The qualitative data

participants found it difficult to understand that the task is planar assembly task. In order to cope with that problem, we gave the floor (brown color in figure 3) and instructed the participants to keep firm contact with the floor.

From the qualitative data (figure 6), it can be seen that all the participants agree that this system helps user to do the assembly task simulation. For the question related to haptic nonhaptic comparison, some participants thought that haptic utilization is not better than using non-haptic application. One of the reasons is that the assembly task and assembled part in this user study are too simple. Users could not feel major benefit from the haptic utilization, since the nonhaptic application can simulate well the simple case without any problem. From the guidance point of view, not all participants agree that the given optimal paths give less effort to do assembly task. For some participants, the existence of given path bothered the movement and needed an effort to follow. This phenomena happened in three path (1th , 5th , 6th path) where the average total times of *guided + sequence* mode are worse than *unguidance sequence* mode. Related to the future and major goal of our research, we asked the participants about opinion on comparison between virtual training and conventional training (physical) system. The yes and no answers share same percentage (50%). Since the whole developed system has not yet been finished, there is still some doubt among the participants about the benefit of virtual training system. To develop a more advanced system to convince the users clearly about the benefits will be our future research objective.

5. Conclusion

A framework for the development of haptic guidance application for the maintenance training purposes has been described. The development of maintenance training applications with haptic guidance contributes to enhance the effectiveness of maintenance training in a virtual environment. All the users agreed that the virtual system can help the assembly process simulation during the maintenance process. Even though the user study was done by using simple assembled parts and planar assembly scheme, the preliminary qualitative and quantitative data is encouraging. The guided and sequence mode gives qualitative and quantitative enhancement compared to the un-guided and without suggested sequence mode.

References

[1] A. Okamura, A. Bettini, S. Lang and G. Hager, " Vision Assisted Control for Manipulation Using Virtual Fixtures: Experiments at Macro and Micro Scales, " Proceeding IEEE International Conference on Robotics and Automation, pp. 3354-3361,2002.

[2] C. Teo, E. Burdet, and H. Lim, " A Robotic Teacher of Chinese Handwriting, " Proceeding Symposium of Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 335-341, 2002.

[3] Y. Wang, Y. Chen, Z. Nan and Y. Hu, " Study on Welder Training by Means of Haptic Guidance and Virtual Reality for Arc Welding, " Proceeding IEEE International Conference on Robotics and Biomimetics, 2006.

[4] F. Conti , F. Barbagli, D. Morris, C. Sewell, " CHAI: An Open-Source Library for the Rapid Development of Haptic Scenes" , IEEE World Haptics, Pisa, Italy, March 2005.

[5] Christiand and J. Yoon, "Intelligent Assembly/Disassembly System with a Haptic Device for

Aircraft Parts Maintenance", Lecture Notes in Computer Science-ICCS 2007. pp. 760-767, 2007.

[6] W. Spong, S. Hutchinson, M. Vidyasagar, "Robot Modeling and Control ", John Willey and Sons, United States, 2006.