VIRTUAL HAND TOOL WITH FORCE FEEDBACK

Ravin Balakrishnan†, Colin Ware† and Tim Smith¶
†Faculty of Computer Science, ¶Dept. of Mechanical Engineering
University of New Brunswick
P.O. Box 4400, Fredericton,
New Brunswick, Canada E3B 5A3
Email: cware@unb.ca

KEYWORDS

Force feedback, haptics, human performance, virtual worlds.

ABSTRACT

We present a system which simulates working with a hand held machine tool on a piece of soft material. A two degree-of-freedom force reflecting joystick allows the user to feel the reactive forces between the virtual toolbit and material. An experiment to investigate the effects on performance in a high precision task when the standard visual display is augmented by our force display system shows a 44% ($p < 0.01$) improvement in accuracy but with time to completion also increased (by 64%). Users of the system find force feedback to be useful and feel that the system is a realistic simulation of the real world task.

INTRODUCTION

A sculptor or machinist working in the real world not only sees the material being worked on but is able to feel the reactive forces between toolbit and material. In a virtual sculpting environment such as that described by Galyean and Hughes [3], only visual feedback is provided and the user is deprived of any haptic feedback. Intuitively it would seem that users of such systems will perform better if the visual display was augmented by a force display system. While it is clear from the literature that for tasks such as molecular docking force feedback can result in up to a two-fold improvement in *speed* [1,5], we are not aware of any published empirical evidence to support the hypothesis that force feedback will improve *accuracy* in a high precision task such as virtual sculpting or machining.

In this paper, we describe a simple 2-D free-form virtual machining system with force feedback. We also present the results of an experiment to investigate if force feedback in addition to visual feedback results in higher accuracy.

SYSTEM OVERVIEW

We use the term 'virtual hand tool' machining to describe the virtual equivalent of a person working on a piece of flat material with a device resembling a Dremel Moto-Tool™. The tool behaves like a milling head and grinds away at any material it comes in contact with. In our system, we represent the material visually as a 300x300 pixel square on the computer monitor and the toolbit as a 10x10 pixel square. Without force feedback, our system is analogous to using an eraser in a paint program. The system runs on a high-end PC and a 14" monitor with a resolution of 800x600 pixels.

Our force display is provided by a two degree-of-freedom joystick designed to be small so as to take advantage of the high precision thumb and forefinger pinch grip (Figure 1). The device is driven by brushless DC servo motors connected by direct mechanical linkages to the joystick shaft. Optical shaft encoders mounted on the motors provide position information to the control software on the PC which computes the required forces in the X and Y directions and sends the appropriate voltages to the motors to create these forces.

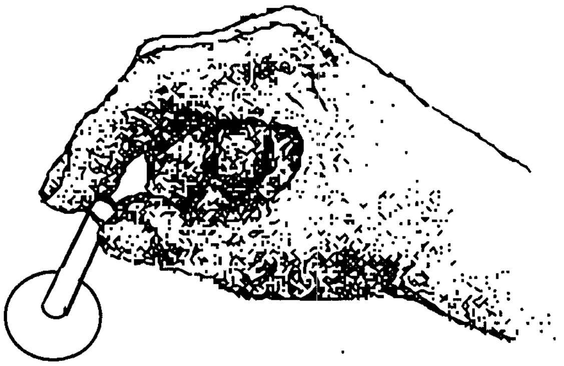

Figure 1. Precision grip joystick

The use of optical shaft encoders, brushless motors and direct mechanical linkages result in a low friction system fairly free of mechanical slop. These factors have been found critical to providing a good illusion of feel [1,4]. Update rate however appears to be an unresolved question -- while Brooks [2] states that the human hand is unable to discriminate between force signals above 320 Hz, Shimoga [6] cites work that claims frequencies of 5-10 kHz are required for high precision tasks. In a texture perceiving task using similar equipment, Minsky et. al. [4] have reported performance differences as the update rate was increased from 500 Hz to 1 kHz, which they attribute to differences in stability of their system at different frequencies. Our system

CHI94 Companion-4/94 Boston, Massachusetts USA

runs at 3 kHz, at which it is both stable and seems to provide a fairly realistic illusion of feel. We have not measured the lag in our system, but estimate it at less than 1 msec.

The use of a square toolbit simplifies force calculations, allowing us to achieve high update rates. The amount of force in each direction is determined by two components: 1) the number of pixels of material in contact with the toolbit up to a maximum of 10, and 2) the cutting rate. As the cutting rate increases the resistance increases in the direction of the cut. This latter component provides an indirect but effective approximation to the amount of force exerted by the operator (i.e., more resistance will be felt if an operator is trying to cut fast and is pressing hard against some material).

EXPERIMENT

Method and Design

In a study designed to determine if force feedback is useful in improving performance in high precision tasks, five paid volunteer subjects were asked to use our system to 'carve' out a pattern representing a human figure overlaid on our virtual material (Figure 2). Each subject carved the pattern once with force feedback and once without force feedback (power to the joystick motors was turned off). Visual feedback was always present. In order to reduce fatigue and learning effects the task was divided into eight parts — subjects worked on a quarter of the material at a time, first with force feedback and then with only visual feedback. Including breaks between the eight parts, the experiment lasted about 30 minutes per subject.

Figure 2. The pattern carved out during the experiment

Performance Measures

Task performance was measured by trial completion time — defined as the time duration from when the trial started till the subject decided that that quadrant was completely carved out, and errors — defined as the number of pixels wrongly cut (i.e., pixels of the figure) and the number of pixels of unwanted material remaining when the trial was completed.

Results and Discussion

Table 1. summarizes the data obtained for all 5 subjects. Comparing the mean errors with and without force feedback shows a 44% improvement in accuracy when force feedback is present. A simple F test on the error data gives $F(1,4) = 27.3$, $p<0.01$, and we reject the null hypothesis that force feedback is insignificant. Interestingly, the mean time taken to complete the task was 64% slower with force feedback. This is probably due to the fact that users feel less restricted when no force feedback is present and thus work faster, however this is obviously at the expense of accuracy.

Method	Force Feedback		No Force Feedback	
Subject	Error	Time(sec)	Error	Time(sec)
S1	1788	662.3	2714	481.8
S2	1590	791.9	1799	498.4
S3	1709	1052.9	2652	461.2
S4	1491	691.8	2139	449.4
S5	1451	611.2	2288	443.9
Mean	1605.8	762.0	2318.4	466.9

Table 1. Performance data for carving entire figure

All the subjects felt that the force feedback was useful and realistic and that it prevented them from making serious errors. They also found our force display system particularly good for carving along smooth lines and curves.

CONCLUSION

We have described a simple force display system coupled to a virtual machining system. An experiment designed to evaluate the benefits of force feedback reveal significant accuracy improvements in a high precision task but at the cost of increased task completion times.

REFERENCES

[1] Brooks, F.P. Jr., Ouh-young, M., Batter, J.J., Kilpatrick, P.J. Project GROPE - Haptic Displays for Scientific Visualization. *Computer Graphics,* Vol 24, No. 4, pp. 177-185, August 1990.

[2] Brooks, T.L. Telerobotic Response Requirements. *Proceedings of IEEE International Conference on Systems, Man and Cybernetics* , pp. 113-120, November 1990.

[3] Galyean, T.A., Hughes, J.F. Sculpting: An Interactive Volumetric Modeling Technique. *Computer Graphics,* Vol 25, No. 4, pp. 267-274, July 1991.

[4] Minsky, M., Ouh-young, M., Steele, O., Brooks, F.P. Jr., Behensky, M. Feeling and Seeing: Issues in Force Display. *Computer Graphics,* Vol 24, No. 2, pp. 235-243, March 1990.

[5] Ouh-young, M., Beard, D.V., Brooks, F.P. Jr. Force Display Performs Better than Visual Display in a Simple 6-D Docking Task. *Proceedings of IEEE Robotics and Automation Conference,* Vol 3, pp. 1462-1466, 1989.

[6] Shimoga, K.B. A Survey of Perceptual Feedback Issues in Dextrous Telemanipulation: Part I. Finger Force Feedback. *Proceedings of IEEE Virtual Reality Annual International Symposium,* pp. 263-270, September 1993