Virtual Machining and Expert Knowledge Capture

Craig Fletcher
School of Engineering & Physical Sciences
Heriot Watt University, UK
(+44) 0131 451 4306
caf7@hw.ac.uk

James M Ritchie
School of Engineering & Physical Sciences
Heriot Watt University, UK
(+44) 0131 451 4364
J.M.Ritchie@hw.ac.uk

Theodore Lim
School of Engineering & Physical Sciences
Heriot Watt University, UK
(+44) 0131 451 4353
T.Lim@hw.ac.uk

ABSTRACT
This paper reports on a virtual haptic machining application for simulating drilling and milling material removal operations; the forces generated during the machining will be conveyed back to the user and any user input via the haptic interface will be logged. This information can then be used downstream in the manufacturing process bringing time cost and quality benefits.

Keywords
Virtual reality, Haptics, Knowledge capture, Machining.

1. INTRODUCTION
There is a genuine requirement for virtual reality systems in industry as "Virtual manufacturing systems provide a useful means for products to be manufactured 'right the first time' without the need of physical testing on the shop floor"[1]. This is particularly applicable to machining as any reduction in time can significantly affect the final product cost.

Virtual Reality (VR) is an artificial environment created in software to give the impression of a real world situation [8] and affords an effective means to rapidly prototype products. VR provides engineers an insight to the problem, gaining better understanding and the ability to share the information with others. Each prototype iteration leads to intrinsic knowledge being acquired for the manufacture process.

Virtual environments are increasingly being extended to include haptic devices [3]. Haptic technology introduces a sense of feel into the virtual environment allowing the operator to interact with virtual objects in a more natural way.

This application will use the Sensable Phantom Omni device as its 6 degrees of freedom can be mapped onto the movement of the majority of machine tools.

Previous work has shown how there is a direct relationship between the time of assembly tasks carried out in a virtual haptic environment and those in reality [2] and other works show that useful data can be logged and analyzed from a design in a virtual environment [9]. This research seeks to extend these works into a machining environment, unobtrusively capturing expert knowledge for later use.

Current simulation algorithms for virtual machining are only as good as the information supplied; however the best understanding on how to manufacture a specific design may not lie with the algorithm designer or CAM software specialist but with an experienced machinist. By unobtrusively logging the machinist's actions in a virtual environment manufacturing information such as the selection of feeds, speeds including the routing strategy can be captured and analysed for its intrinsic and extrinsic values.

Digital Engagement '11, November 15 – 17, 2011, Newcastle, UK.

2. APPLICATION ARCHITECTURE

2.1 Hardware Architecture
The hardware set up includes a Sensable Phantom Omni device (Figure 1), Dell T1500 Workstation, including INTEL CORE I5-750(2.66GH) CPU, 4GB 1333MHZ DDR3 RAM, NVIDIA Quadro FX580 GPU.

Figure 1 Haptic device

2.2 Software Architecture
The software consists of a multi-threaded application, with the graphics, physics engine and haptics running in separate threads (Figure 2). The haptic application requires 1kHz rendering frequency to reproduce forces convincingly. Software libraries used include OpenSceneGraph [5], ODE [4], osgModelling [6] and OpenHaptics [7].

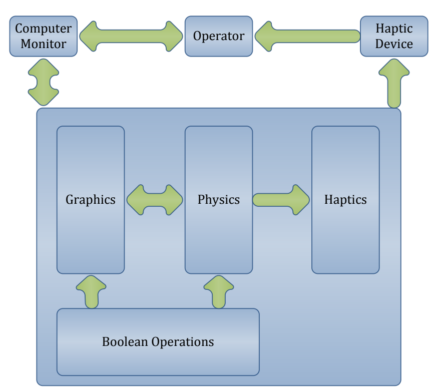

Figure 2 Software architecture

3. INITIAL TESTS

Simulating the drilling and milling of a virtual billet was carried out as an initial proof of concept (Figure 3). The user can pick and manipulate the billet into place, then drill or mill the billet with haptic forces being fed back. All haptic interactions are logged for downstream automation such as manufacturing process planning.

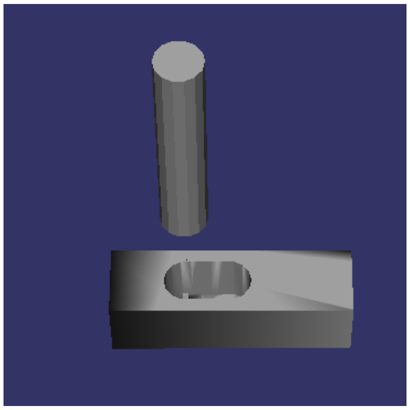

Figure 3 Milling operation

4. RESULTS

The logged information which represents captured expert knowledge consists of all Newtonian and Eulerian mechanics active in the haptic workspace (Figure 4). This is post processed into a more useful format (Figure 5).

1	Time(s)	L_Position(x)	L_Position(y)	L_Position(z)
2	Start Manipulation			
3	9	-14.22	-21.19	-26.54
4	Manipulating			
5	7163	-14.22	-21.19	-26.54
6	Manipulating			
7	61275	-527	-785.2	-982.5
8	Manipulating			
9	122167	-523.9	-780.2	-975.7

Figure 4 Samples of logged data

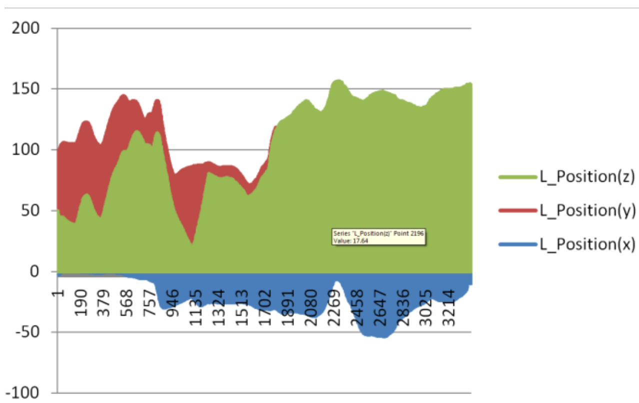

Figure 5 Line graphs of logged data showing object manipulation

In order to log accurate information it is important that the simulation runs in real time. This is difficult to achieve in haptic virtual environments where haptic and material removal operations are processor intensive. Table 1 presents the frame rate against the haptic operations.

Table 1 Results of haptic operations

Haptic Operation	Frame Rate (frames/sec)	Triangle Count
Manipulation	60	164
Drilling	46	64->140
Milling	18	140 ->338

5. CONCLUSION AND FUTURE WORK

The interface is intuitive, easy to use and allows expert manufacturing knowledge (e.g. set up, feedrate, etc.) to be unobtrusively captured; however realism needs to be improved to provide a more convincing virtual representation.

Currently rendering of the material removal is not carried out in real time. True volumes and mass properties are required so the Mesh Boolean operations are carried out in blocks to keep the frame rate up. The haptic forces representing the scaled vibratory and tool/material cutting resistance requires further development in order to be made more distinguishable over the range and permutations of machining parameters.

Future work will include:

- Speed up Mesh Boolean operations.
- Measure and include real world forces generated during milling and drilling
- A framework would be useful allowing similar applications to be built with other graphical renderers, physics engines, audio and other material removal methods.

6. REFERENCES

[1] Abdul Kadir, A. et al. 2011. Virtual machine tools and virtual machining--A technological review. *Robotics and Computer-Integrated Manufacturing*. 27, 3 (Jun. 2011), 494-508.

[2] Lim, T. et al. 2007. Factors affecting user performance in haptic assembly. *Virtual Reality*. 11, 4 (Oct. 2007), 241.

[3] Lin, M.C. and Otaduy, M. 2008. *Haptic Rendering: Foundations, Algorithms and Applications*. A K Peters.

[4] Open Dynamics Engine - home: *http://www.ode.org/*.

[5] osg: *http://www.openscenegraph.org/projects/osg*.

[6] osgmodeling - A modeling library for OpenSceneGraph, *http://code.google.com/p/osgmodeling/*.

[7] Sensable: *http://www.sensable.com/*..

[8] Sherman, W.R. and Craig, A.B. *Understanding Virtual Reality: Interface, Application, and Design*. Morgan Kaufmann.

[9] Sung, R.C.W. et al. 2011. Knowledge Capture inside a Haptic Soldering Environment. *Proceedings of the 6th International Conference on Virtual Learning, Workshop on Haptic Feedback Systems in Education*. (Oct. 2011).