Haptic Feedback to Guide Interactive Product Design

Andrew Fischer   Judy M. Vance   Dao M. Vo

Virtual Reality Applications Center
Department of Mechanical Engineering, Iowa State University

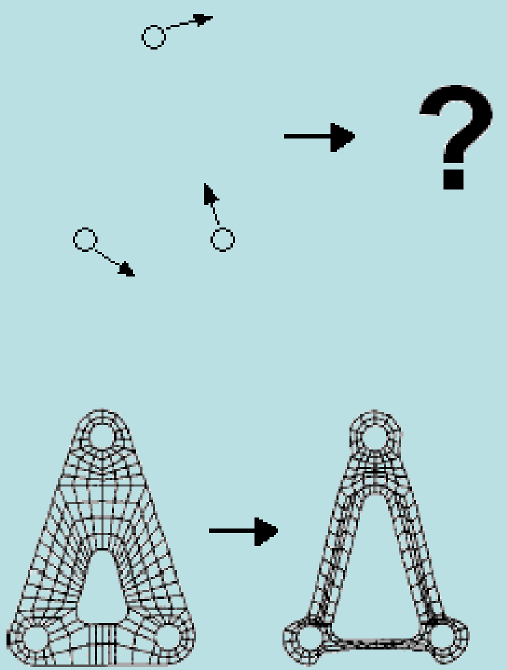
World Conference on Innovative VR (WinVR09)
February 25-26, 2009
Chalon-sur-Saone, France

Introduction

Research Goal: Develop effective methodology for interactive product design using virtual reality (VR)

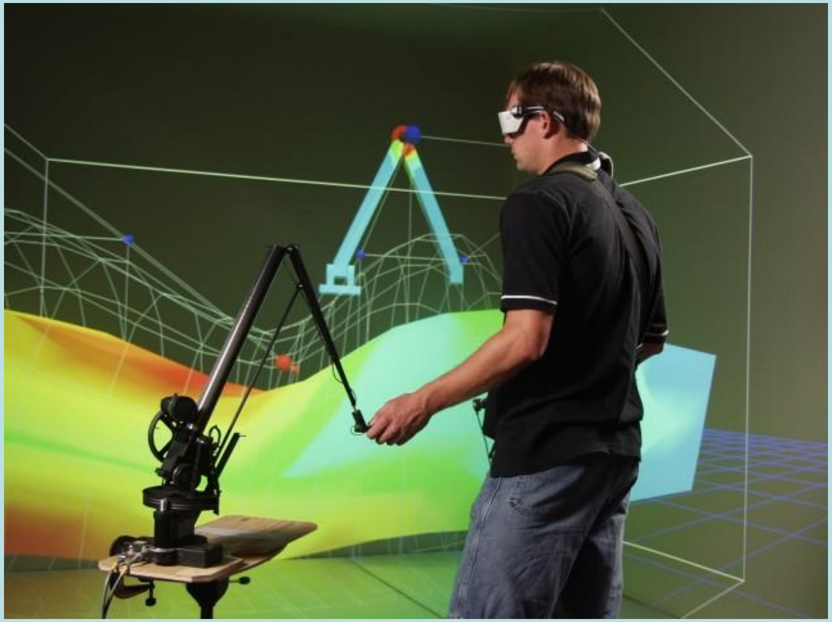
Motivation

- Early design phase
- Couple design and analysis
- Take advantage of VR
- Explore alternatives



Immersive Virtual Design Application - IVDA

To allow the designer to interactively change the shape of a product within a virtual environment and examine the effect that shape change has on the stresses generated in the product



Methodology

- Create a CAD model
- Perform a finite element stress analysis

- Display CAD model with stress analysis in VR
- Create a bounding volume around the area where shape changes are acceptable
- Move the bounding volume to change the shape of the part. New approximated stresses are calculated and displayed.
- Investigate the effect of multiple shape changes on the stresses induced in the part

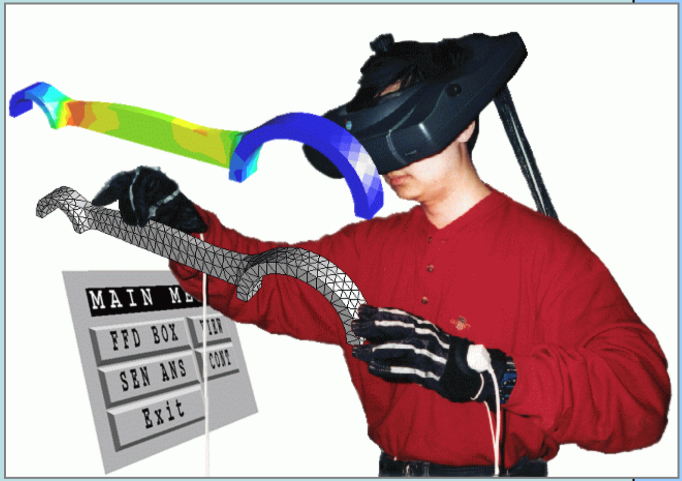
---

- Remodel in CAD
- Perform new finite element stress analysis

Background – Yeh & Vance 1998

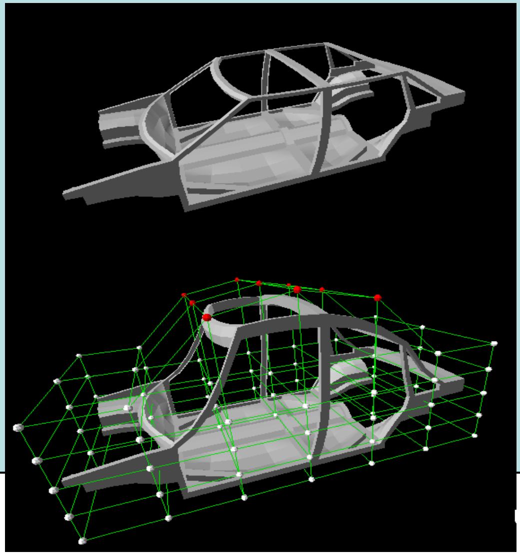
Method

- Free-form deformation of models (NURBS bounding volume)
- Stress changes as shape does
- Taylor series approximation of stress deformation



Limitations

- Low accuracy
- Relies on pre-computed stress sensitivities outside VR

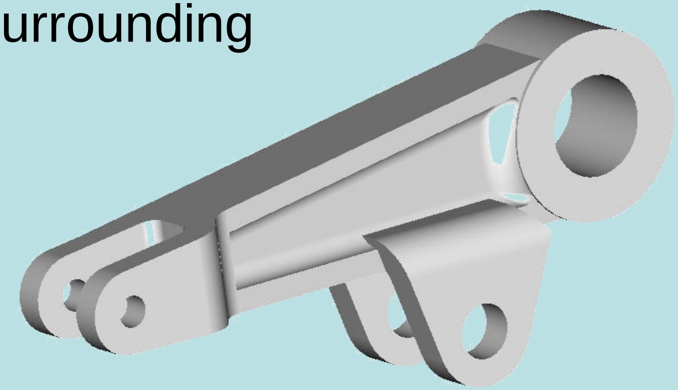


WINVR 09

Background – Ryken & Vance 2000

Application

- Industrial problem from John Deere
- Implemented in C2 virtual environment
- VR aided design of complex shape
- Collision detection between new shape and surrounding parts

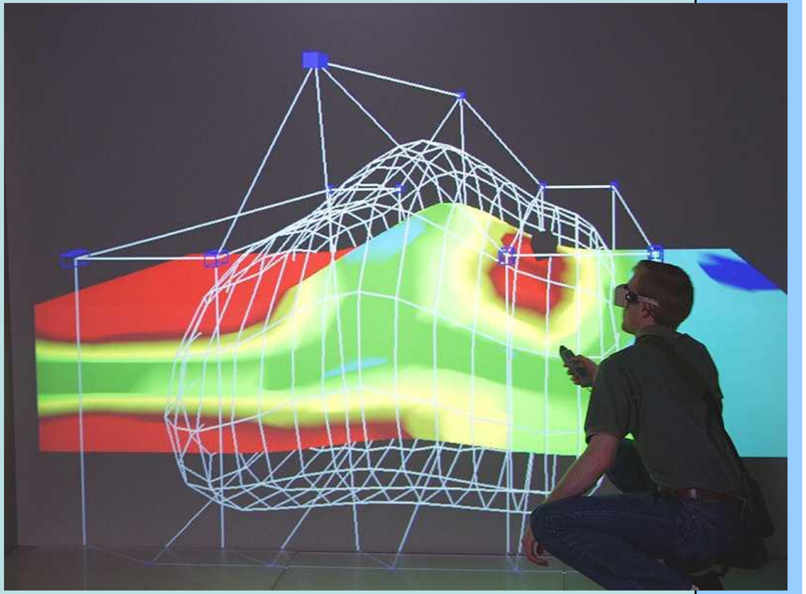


Background – Chipperfield, Yeh & Vance 2006

Subdivision Volume free-form deformation

PCG reanalysis

- Quickly re-solves stiffness equation
- Compute new sensitivities
- Results in two stage approach

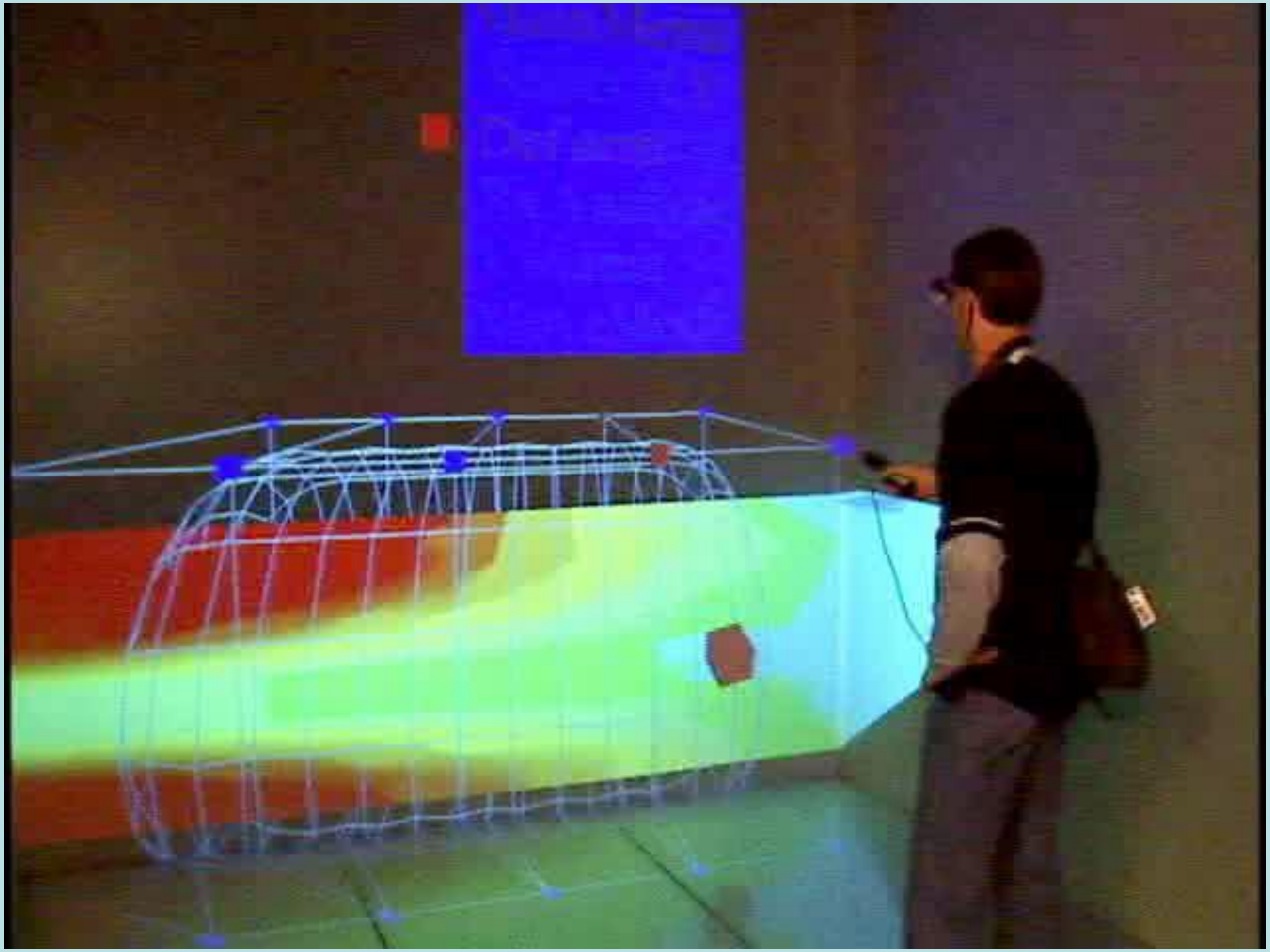


Mesh-free analysis

- Avoid element distortion

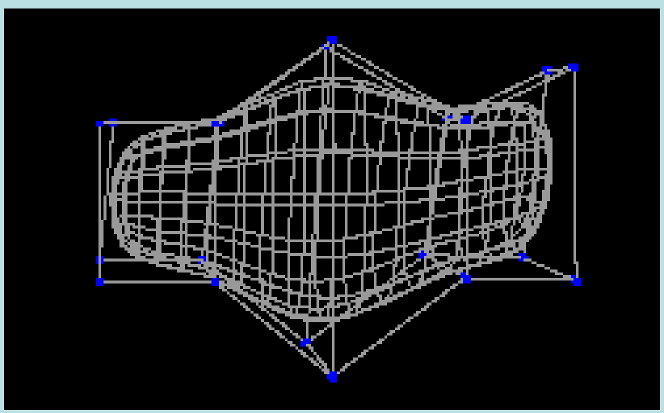
VRJuggler platform – Open Source

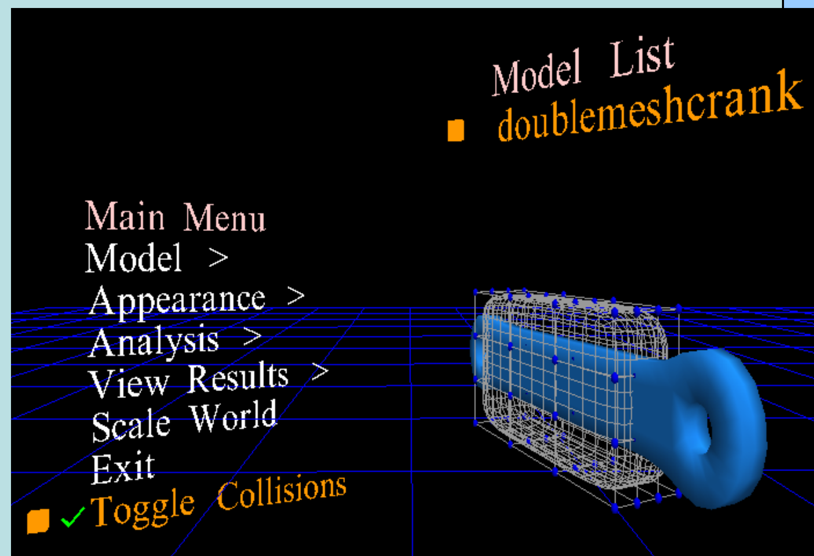
WINVR 09



Immersive Virtual Design Application - IVDA

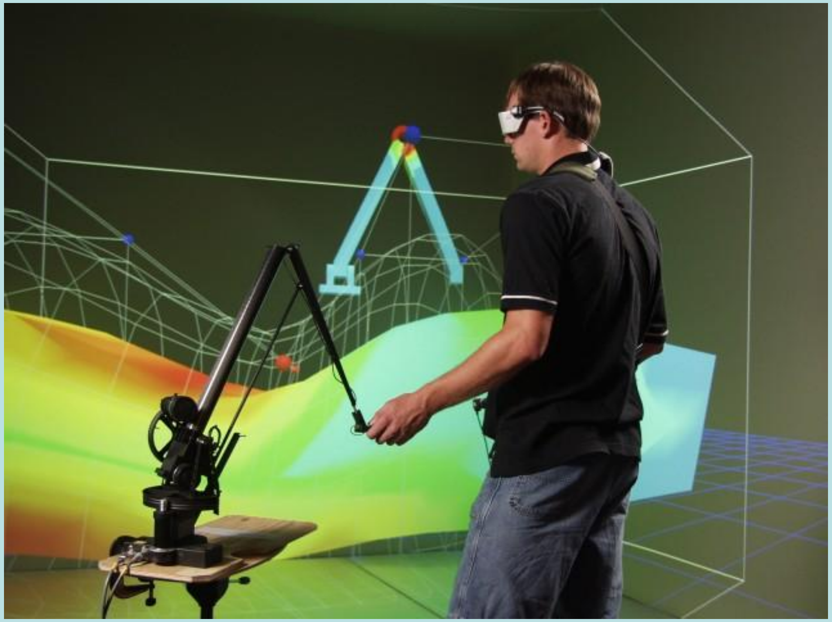
- Catmull-Clark subdivision volumes
- Open Source PCGA solver: Tahoe
- Haptic integration



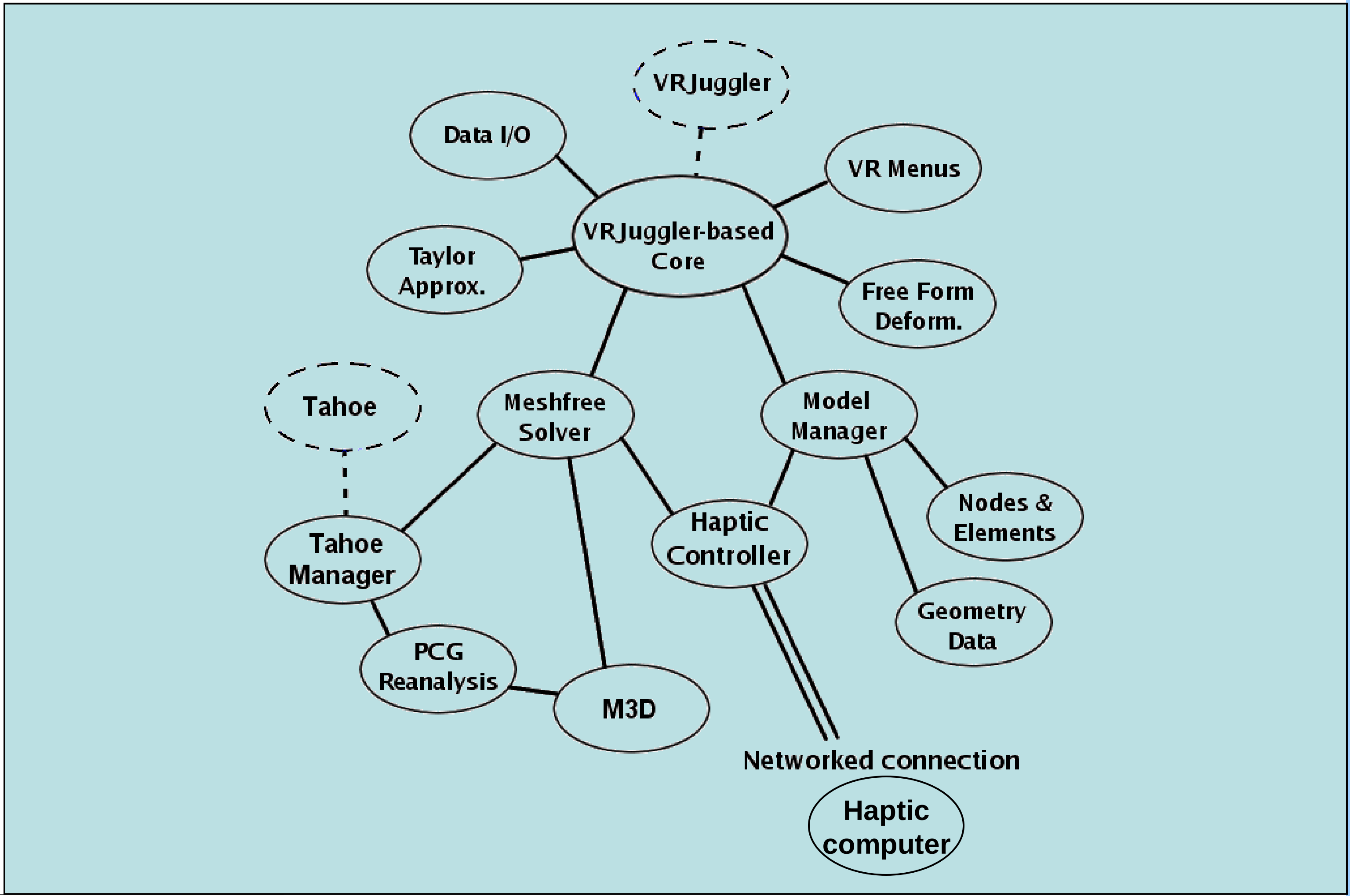


Haptic Integration

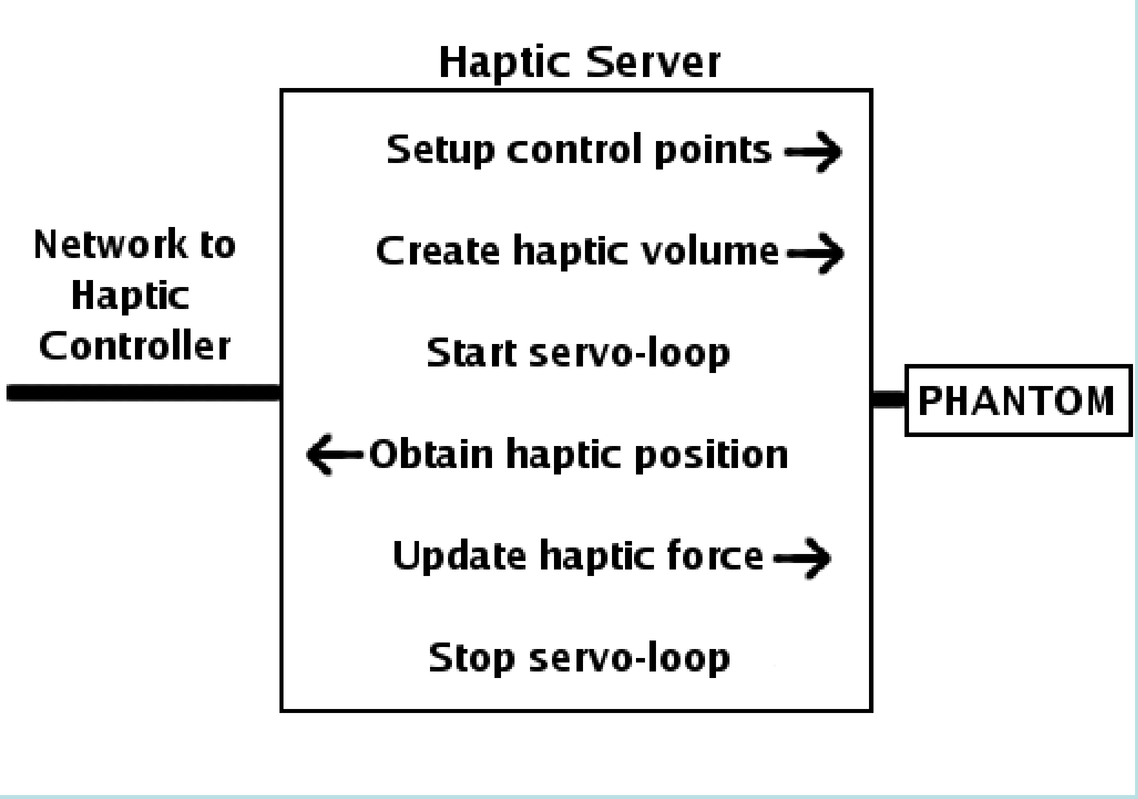
- Aid designers in relating deformations to stress contours
- Provide an additional feedback channel
- Use the PHANTOM 3.0 in a virtual environment



Configuration



Haptic Computer



Haptic Modeling

Challenge

- Convert the stress state into a value for the haptic device

Tahoe returns either Von Mises stress or Maximum Shear Stress for each element

First method

Model the feedback as the global mean of all stresses in the model

$$\gamma = \sum_{i=1}^{N} \sigma_{VM}(i)$$

Second Method

Model the feedback as proportional to the stress sensitivities

$$\gamma = \sum_{i=1}^{N} \bar{h}(i)\sigma_{VM}(i)$$

where

$$\bar{h} = \frac{h_x + h_y + h_z}{3}$$

Normalize feedback value

$$\gamma_{haptic} = \frac{\gamma - \gamma_{\min}}{\gamma_{\max} - \gamma_{\min}}$$

Model Forces

$$m\frac{\partial^2 x}{\partial t^2} + b\frac{\partial x}{\partial t} + kx = F$$

- Adjust mass term

Only affects the force through the acceleration term

- Adjust damping term

Generates a viscous friction-like effect to resist motion

- Adjust spring term

Generates a direct spring force to resist motion

Pilot study

- Determine if a user perceives any benefit from force feedback tied to the stress levels in the deforming model
- Determine if there is a user preference between the damping model of force or the spring model of force

Setup

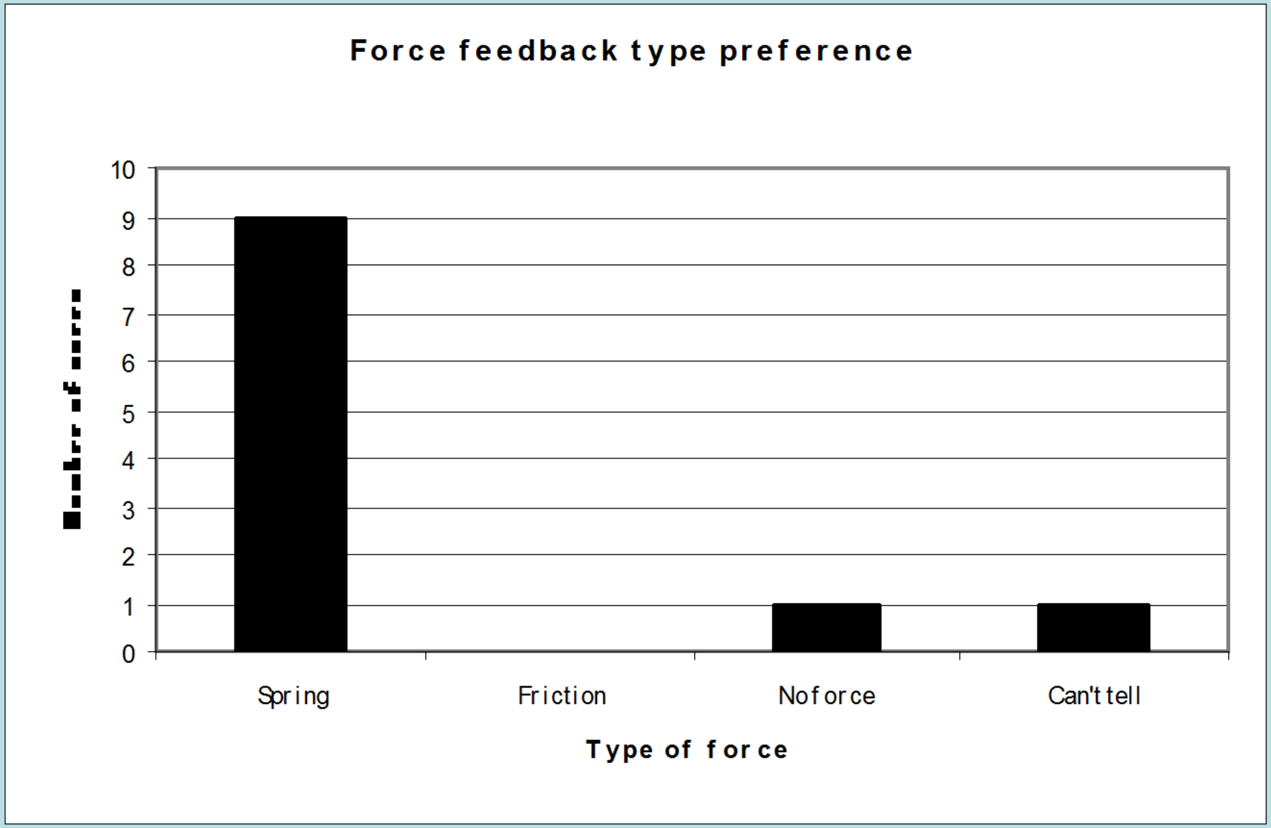
- 11 users
- Students with varying experience with video game usage
- Pre-study questionnaire
- Post-study questionnaire
- Simple beam model, already loaded with bounding volume defined, stress averaging method
- Desktop VR
- Active stereo glasses

Task

Participants were asked to deform the model using the haptic device.

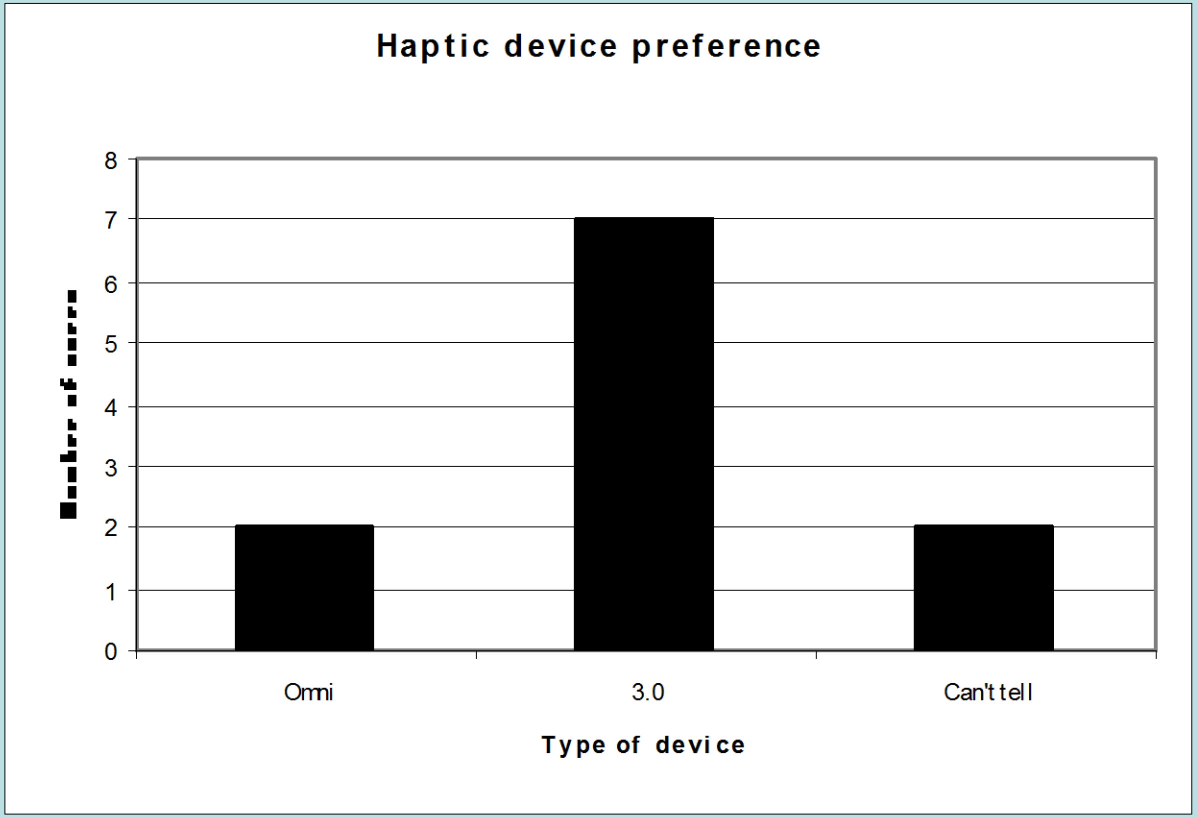
- Spring force
- Damping force
- Omni device
- Phantom 3.0 device

Results



Force feedback type preference
10
9
8
7
6
5
4
3
2
1
0
Spring
Friction
No force
Can't tell
Type of force

Results



Haptic device preference
8
7
6
5
4
3
2
1
0
Omni
3.0
Can't tell
Type of device

Conclusions

- Since forces were related to stresses, and not necessarily deformation, it was difficult to process when the visual feedback conflicted with the force feedback
- Spring forces gave better feedback than viscous forces
- Participants preferred the larger workspace haptic device

Acknowledgements

National Science Foundation

IIS-0552522 Research Experience for Undergraduate Students