Virtual Reality as an Interface to Mechanical Design

Judy M. Vance, PhD
Professor
Mechanical Engineering Department
Iowa State University
Virtual Reality Applications Center
Ames, IA

February 3, 2010
Virtual Reality Applications Center

To be a national leader in the application of virtual reality to the challenges of science and engineering
The Virtual Reality Applications Center

An interdisciplinary research center focusing on the rapidly expanding interface between humans and computers.
Virtual Reality Applications Center

- $23M in contract funding
- 50 active interdisciplinary projects
- 40 faculty investigators from 7 colleges
- 190 graduate & undergraduate researchers
- Sponsors
  - Industry
  - DoD
  - Other Federal
  - Other Federal
Human Computer Interaction (HCI) Graduate Program

PhD and MS programs in Human Computer Interaction

68 HCI Faculty members who come from
- College of Design
- College of Engineering
- College of Liberal Arts and Sciences
- College of Human Sciences
- College of Business
Research Mission: HCI

- Mobile
- Wireless
- Virtual Reality
- Augmented Reality
- Wearable
- Haptics
- Teleoperation

Convergence
C6
Six-sided Immersive Environment
C6

Six-sided Immersive Environment

10 ft. x 10 ft. x 10 ft.
49 dual core processor computers
  96 processors run the C6
96 graphics cards
24 Sony 4k SXRD digital projectors
100 million pixels total
  16.7 million pixels per wall
4096 x 4096 resolution for each eye
Networked Haptic Environment
Haptics Implemented in a Projection Screen Virtual Environment
Collision detection
Physics-based modeling
Dual-handed haptic interface
Complex CAD model assembly
Subassembly support
Swept volumes
Network communication
Portable to different VR Systems
Dual-handed Haptic Assembly

Sharp Final.wmv
Mechanism Design

- Spherical (VEMECS, Isis)
- Spatial (VRSpatial)
- Compliant

Haptics

- Dual Handed Haptic Assembly System (SHARP)
- Networked Haptic Environment (NHE)
- Implementing Haptics in a Large Projection Screen Environment
- Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics
- A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

Other

- Hydraulic Hose Routing in VR
- Interactive Stress Analysis in VR (M3D, IVDA)
- Discrete Event Simulation in VR
Mechanism Design

- Spherical (VEMECS, Isis)
- Spatial (VRSpatial)
- Compliant

Haptics

- Dual Handed Haptic Assembly System (SHARP)
- Networked Haptic Environment (NHE)
- Implementing Haptics in a Large Projection Screen Environment
- Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics
- A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

Other

- Hydraulic Hose Routing in VR
- Interactive Stress Analysis in VR (M3D, IVDA)
- Discrete Event Simulation in VR
Current Projects

Constraint-based Compliant Mechanism Design using Virtual Reality as a Design Interface

A Hybrid Method to Support Natural Interaction of Parts in a Virtual Environment

The focus of research in the Vance group is on the use of haptics and immersive VR technology to improve the product design process. We are developing methods to support low clearance CAD model assembly with realistic force feedback to support virtual assembly process evaluation and new design methodology for compliant mechanism design.

Virtual Training, Assembly and Maintenance Methods

Judy M. Vance, 2010
Constraint-Based Synthesis of Shape-Morphing Structures in Virtual Reality

Denis V. Dorozhkin
Judy M. Vance
Compliant Mechanisms

Achieve motion guidance via the compliance and deformation of the mechanism’s members

Successful design of compliant mechanisms requires an understanding of solid mechanics (deformation, stress, strain, etc.) and mechanism kinematics (properties of motion)

Image © PCSL, MIT
Shape-morphing Compliant Structures

Geometric shapes of the individual system components, such as aircraft wings and antenna reflectors, directly affect the performance of the corresponding mechanical systems.

The goal is to design a single-piece flexible structure capable of morphing a given curve or profile into a target curve or profile while utilizing the minimum number of actuators.
Current Research

Pseudo-Rigid Body Modeling
Primarily aimed at modeling rather than synthesis


Topological Synthesis
Designers have little control over the resulting solution (overly-complex topologies)

Constraint-based Design Method (CBDM)

- Fundamental premise - all motions of a rigid body are determined by the position and orientation of the constraints (constraint topology) placed upon the body.
- Any mechanism motion path may then be defined by the proper combination of constraints.
CBDM Shape Morphing

- Flexible element that comprises the active shape surface is discretized at multiple points in both the initial and the target configurations.
- Individual elements are then treated as 3- or 6-DOF rigid bodies that undergo a planar or general spatial displacement.
- Goal is to identify the number and the topology of the constraints that will impart these motion characteristics.
Model the compliant mechanism as a series of cells composed of 4-bar rigid link mechanisms.
Determine approximate location for anchor points

- Vary the location of the anchor points within the available anchor region, and change the value of the input angle within the specified bounds, while computing the cumulative difference from the reference profile.
- Optimize to reduce error between desired shape and original shape.
Final Anchor Point Locations

- Discard the rigid-body approximation, and model the structure using finite element methods
- Repeat optimization using the refined anchor regions and computing compliant structure response
VR Application

Lumbar support stress animation.avi
Future Work

• Real-time haptic interaction with the deformable structure
• Non-planar shape morphing compliant structures
• Secondary design modules
  – Sensitivity analysis
  – Manufacturing tolerance/process analysis
Virtual Assembly

Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics
Virtual Manual Assembly for Low Clearance Parts
Haptic Interaction for Large Area Virtual Environments
Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics

Patrick Carlson
Vikram Vyawahare
Judy M. Vance
Motivation

Research has shown that we naturally use our “non-dominant hand” to select and manipulate objects while we use our “dominant hand” to perform fine motor skill.
Approach

Use a non-haptic glove on the non-dominant hand
Provide a haptic device for interaction with the dominant hand

Expands the workspace of the haptic device
Allows us to perform two handed interaction for less cost
User Study

Hardware
  • 2 x Phantom Omni from Sensable
  • 5DT Data Glove
  • Patriot Tracker from Polhemus
  • 120 Hz projector display for stereo
  • Crystal Eyes active stereo glasses

Software
  • VRJuggler
  • Voxel Point Shell (VPS) for collision detection
User Study Variables

Dependent Variable
- Time taken for task

Independent Variables
- Device Configuration
  - Haptic - Haptic
  - Nonhaptic – Haptic
  - Glove - Haptic
- Hand (dominant / nondominant)
- Task (simple / hard)
## Research Approach

<table>
<thead>
<tr>
<th></th>
<th>Haptic-Haptic (Omni-Omni)</th>
<th>Nonhaptic-Haptic (Omni-Omni)</th>
<th>Glove-Haptic (Glove-Omni)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simple Task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonhaptic in dominant hand</td>
<td>Nonhaptic in nondominant hand</td>
<td>Glove in dominant hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Glove in nondominant hand</td>
</tr>
<tr>
<td><strong>Hard Task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonhaptic in dominant hand</td>
<td>Nonhaptic in nondominant hand</td>
<td>Glove in dominant hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Glove in nondominant hand</td>
</tr>
</tbody>
</table>
Hypothesis

Remove haptic ability from non-dominant hand
  - Results in equal or better performance than haptic enabled devices in both hands.

Use of glove in non-dominant hand and haptic device
  - Results in the best performance.
User Centered Haptics for Virtual Assembly

Vikram Vyawahare
Judy M. Vance
Putting it all together

Immersive displays
Whole body tracking
Haptics for large work areas
Bimanual Interaction
Human Scale Haptics

Combine

• Virtuose 6D-35-45 from Haption
• Mobile platform
• 5DT data glove

Implement in a large scale projection screen environment
Combining Physical Constraints with Geometric Constraint-Based Modeling for Virtual Assembly

Abhishek Seth
Judy M. Vance
Sample Assembly Task

Realistic Representation

Tactile Force Feedback
Depth Perception

Dexterous & Intuitive Manipulation

Realistic Part Behavior
Realistic Part Behavior
Simulating Physical Collision + Tactile force feedback Constraints
Precise Part Manipulation
Research Challenges

- Realistic environment behavior
  - Real-time visualization
  - Collision detection
  - Physics-based modeling
- Intuitive interaction
- Support for complex CAD geometry
- CAD system independence
- Direct CAD-VR data transfer
- Portability to different VR systems
SHARP Assembly Results

• Advantages
  – Realistic environment behavior
  – Intuitive interaction
  – Complex CAD geometry support
  – CAD system independence
  – Portability to VR systems
  – Haptic feedback

• Limitations
  – CAD model approximation using voxels
  – Low clearance assembly not possible
  – System insensitive to features smaller than voxel size
  – Large and small part assembly not possible
  – High memory & computation requirements
  – Limited number of parts in the environment
Challenges Redefined

- Realistic environment behavior
  - Real-time visualization
  - Collision detection
  - Physics-based modeling
- Intuitive interaction
- Support for complex CAD geometry
- CAD system independence
- Direct CAD-VR data transfer
- Portability to different VR systems
- Low clearance assembly
- Large and small parts in the environment
- Highly accurate collision detection & physics modeling
Addressing New Challenges

- Precise CAD model representations (B-Rep)
  - Collision detection
  - Physical Constraint Simulation

Voxel, tri-mesh and B-Rep representations of a model
Initial Results

- Advantages
  - No approximation
  - Very accurate collision/physics response
  - Successfully handle complex CAD data

- Case 1 - Collision Only

Low clearance assembly in SHARP
Initial Results

• Case 2 – Collision + Physical Constraints
  – Successfully simulate realistic part behavior
  – Difficult to assemble low clearance parts with small clearance
  – Precise part movements can’t be achieved
  – Intermittently occurring simultaneous contacts affect system performance
Constraint-Based Modeling

- Uses predefined relationships among geometric features
- Computes reduced degree-of-freedom of parts
- Allows precise part manipulation

<table>
<thead>
<tr>
<th></th>
<th>Constraint-Based Modeling</th>
<th>Physics-Based Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Computation Load</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Precise Part Movement</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Prevent Part Interpenetration</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Realistic Behavior Simulation</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Automatic Constraint Recognition

• Feature-based approach
  – Monitors exact contacting geometries (faces/edges) during assembly to predict user’s assembly intent
  – Identifies, adds and deletes geometric constraints automatically
hybrid_voice.wmv
Summary

- Realistic part behavior
- Support for different VR systems
- Dual-handed haptic interface
- Ability to handle arbitrary CAD data
- Direct data transfer from CAD - VR
- Highly accurate collision/physics responses
- Runtime definition of geometric and physical constraints
- Feature-based automatic constraint recognition
- Low clearance assembly possible (0.001% clearance)
- Intuitive user interaction
- Optimized system performance

SHARP running in a six-sided CAVE System
Future Work

• Limitations
  – System performance when handling large assemblies
  – Haptic Interaction

• Future Work
  – Using tri-mesh data for collision detection
  – Combining constraint management with open-source dynamics engines
  – Design modifications in VR
A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

Develop and evaluate a new hybrid method of collision detection and haptic modeling that will more realistically simulate natural interaction of low clearance parts in a virtual environment.
Voxmap PointShell Method

Developed by McNeely, Puterbaugh, Troy at Boeing
Hybrid Approach

- Use voxels to carry BREP data
- Voxel-pointshell collision returns BREP data
  - Automatic constraint recognition to guide parts
- Force blending required to smooth voxel-based and constraint-based forces and torques
Hybrid Method Assembly Sequence

1. Collision occurs:
   Identify faces and edges

2. Constraints determined based on identified faces or edges

3. Constraints activated:
   calculate new position

4. Calculate new collision and constraint forces and torques
Thank You