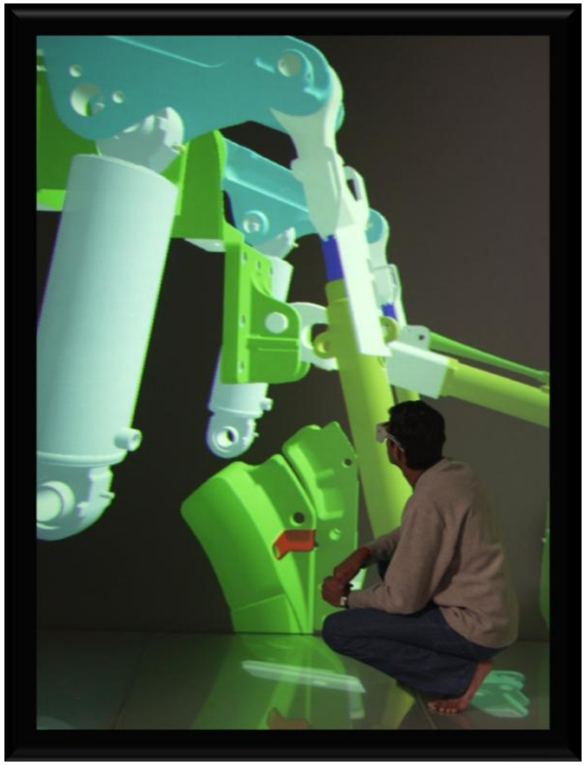
Low Clearance Assembly of CAD Models with Haptic Feedback



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

Pennsylvania State University
February 24, 2010

Vance Research Areas

Mechanism Design within an Immersive Virtual Environment
- 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
- Ergonomic Data Exploration and Design Tools in VR

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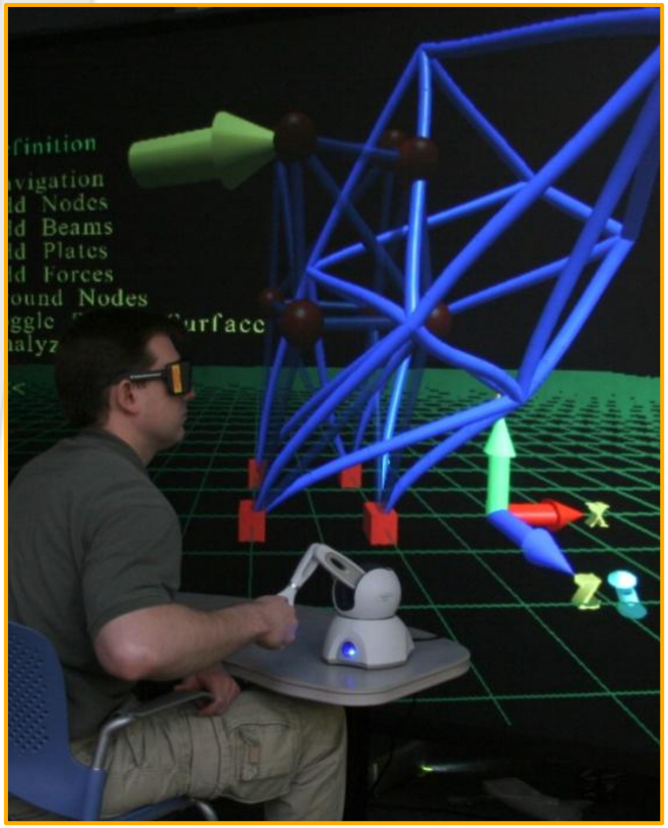
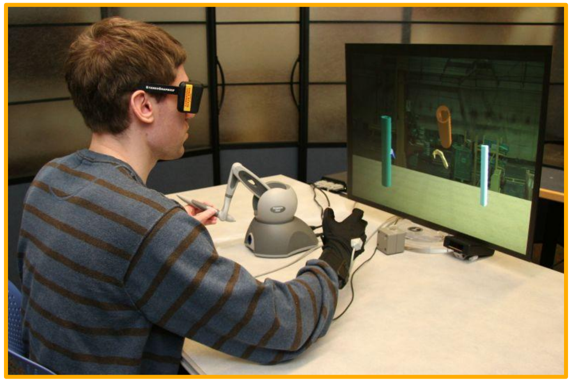
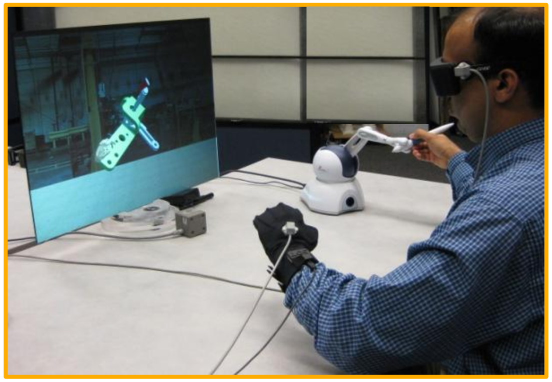
Current Projects

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



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



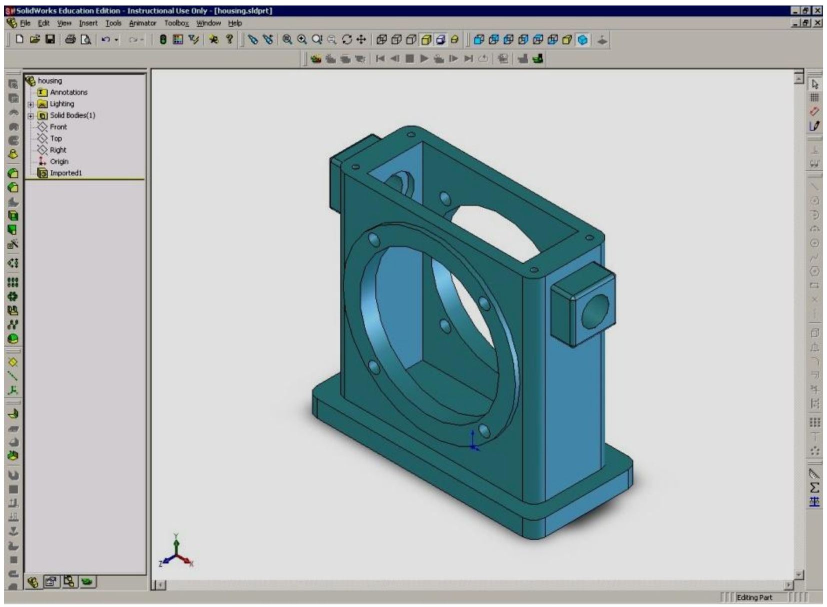


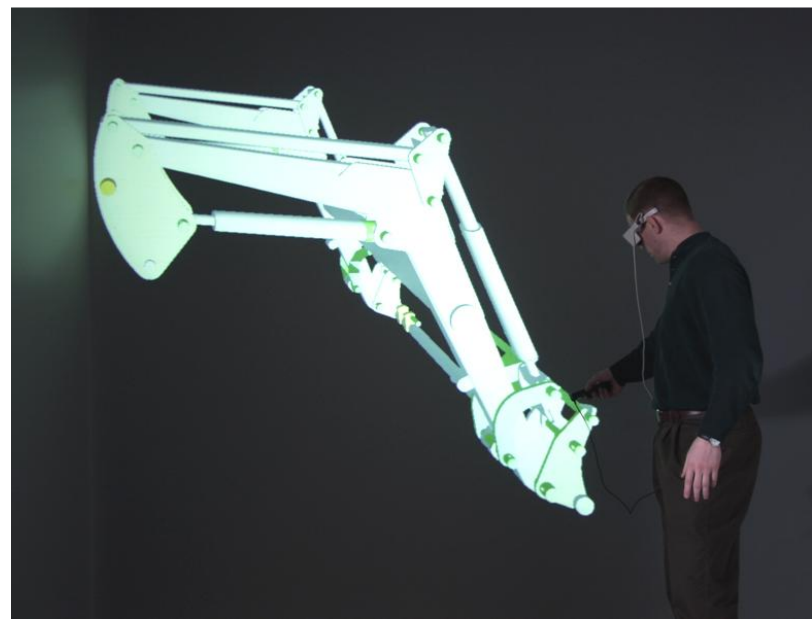
The focus of research in the Vance group is on the use of haptics and immersive VR technology to improve the product design process. We are developing methods to support low clearance CAD model assembly with realistic force feedback to support virtual assembly process evaluation and new design methodology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

Virtual Training, Assembly and Maintenance Methods

Virtual Assembly

Objective: Research methods and algorithms that integrate natural human interaction into the CAD model assembly process.





“The ability to interact with synthetic entities as if they were real has been the ultimate quest of virtual reality (VR) researchers for decades.”

Miguel A. Otaduy and Ming C. Lin, *High Fidelity Haptic Rendering*, 2006, Morgan & Claypool, p. 1.

Vision

Customers provide feedback to companies on potential products before design is complete

Designers validate assemble-ability, maintainability, reusability, ergonomics, and product safety.

Manufacturing Engineers prototype assembly methods, evaluate ergonomics in assembly, design tools, fixtures, and facilities, and perform assembly line balancing

Assemblers prototype assembly methods and give feedback prior to finalized product, tool, fixture and facilities design

Put the Human in the Simulation

- Are handling tools required?
- Is access for part, tool or hands obstructed?
- Is vision of the mating surfaces restricted?
- Is holding down required to maintain the part orientation or location during subsequent operations?
- Is the part easy to align and position?
- Is the resistance to insertion sufficient to make manual assembly difficult?
- Can the part be grasped in one hand?
- Do parts nest or tangle?
- Are parts easy or difficult to grasp and manipulate?

Boothroyd, Dewhurst, Knight 1994

Haptics

Haptics: from the Greek *haptesthai*, meaning "*to touch*"

- Cutaneous touch
- Kinesthetic touch

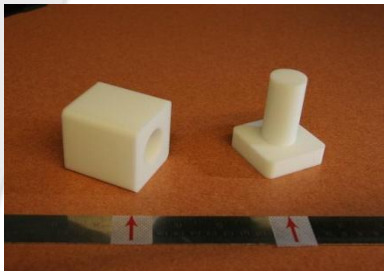
Haptic rendering involves computing and generating forces based on user interaction with virtual objects

Integration of haptics into VR involves many different research areas including computer graphics, collision detection, dynamic simulation, psychophysics, control theory, and robotics

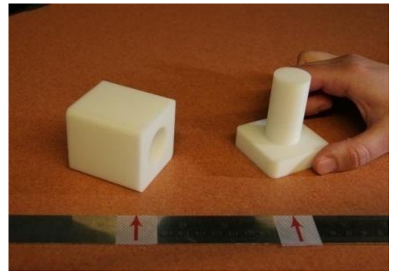
Cross-modal Interaction

Haptics increases situational awareness and improves performance when integrated into a virtual environment

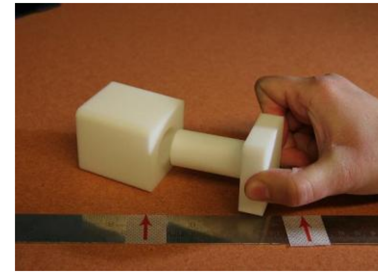
Task Requirements



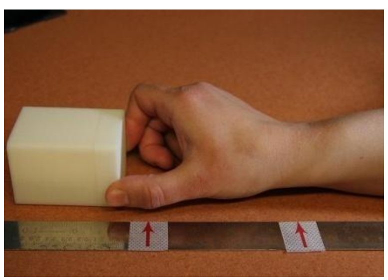
Realistic
Representation



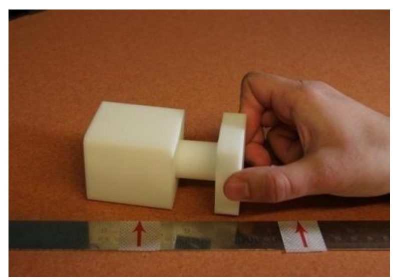
Tactile Force Feedback
Depth Perception



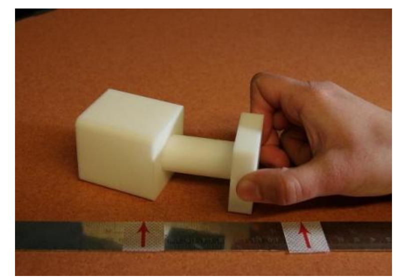
Dexterous & Intuitive
Manipulation



Realistic Part Behavior



Realistic Part Behavior
Collision + Tactile force feedback
Precise Part Manipulation



Simulating Physical
Constraints

Research Issues

Collision detection

- Large, complicated CAD models
- Performance to support real time (interactive) collisions
- Low clearance assemblies

Force rendering

- Physics simulations to support part interaction
- Demanding computational requirements to maintain haptic refresh rates

Haptic devices

- Limited workspaces
- Limited force and torque capabilities

Previous Work

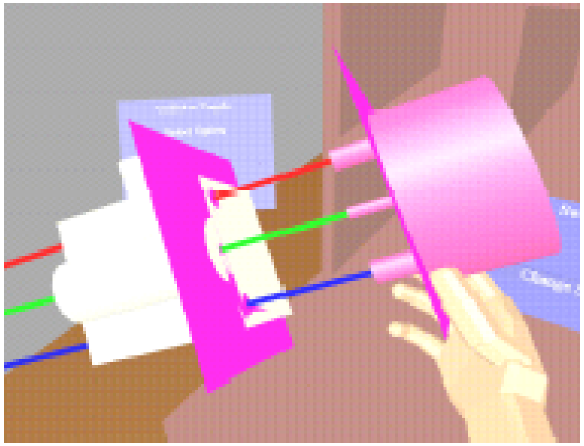
Constraint-based Assembly

Positional Constraints

- Kuehne & Oliver 1995
- Pere, Langrana, Gomez & Burdea 1996
- Ye, Banerjee, Banerjee & Dech 1999
- Gomes de Sá & Zachmann 1999
- Bullinger, Richer & Seidel 2000

Geometric Constraints

- Fa, Fernando & Drew 1993
- Jung, Latoschik & Wachsmuth 1998
- Marcelino, Murray & Fernando 2003
- Wan, Gao, Peng, Dai & Zhang 2004
- Singh & Bettig 2004
- Jayaram et al. 1999 to 2007
- Liu and Tan 2005, 2007
- Yang, Wu, Fax & Yan 2007



Constraint Based Assembly in VADE

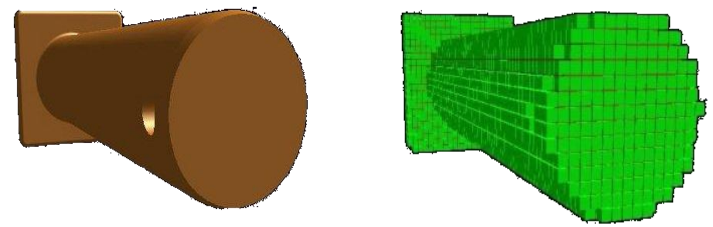
Previous Work

Physics-based Modeling

- Gupta, Whitney & Zeltzer 1997
- Frohlich, Tramberend, Beers, Agarawala & Baraff 2000
- Coutee, McDermott & Bras 2001
- Kim & Vance 2004
- Seth, Su & Vance 2005, 2006
- Garbaya & Zaldivar-Colado 2007
- Ritchie, Lim, Sung, Corney & Rea 2008

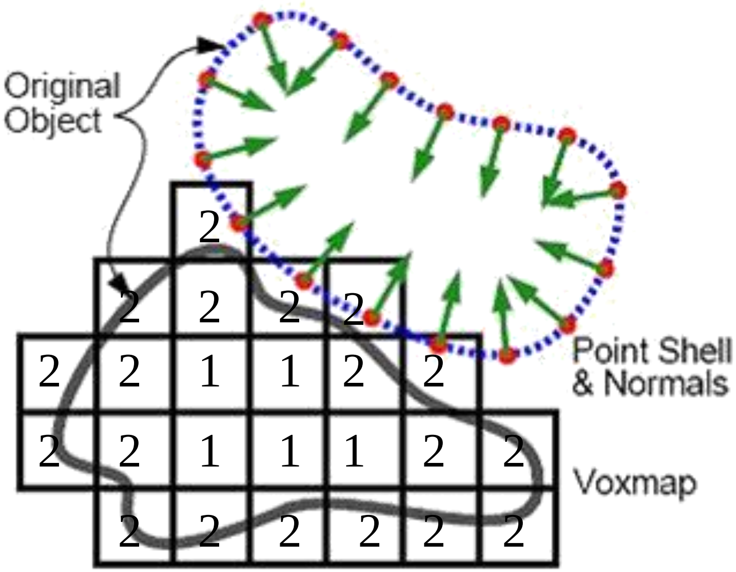
Seth, A., Vance, J. M., Oliver, J. H., "Virtual reality for assembly methods prototyping: A review," *Virtual Reality Journal*, Special issue on Construction and Manufacturing, published online 2010, in press 2010.

Voxmap-Pointshell Method



3D geometry is discretized into 3D voxels

A voxel-based distance field is created with voxels identified by integers representing the distance to the interior

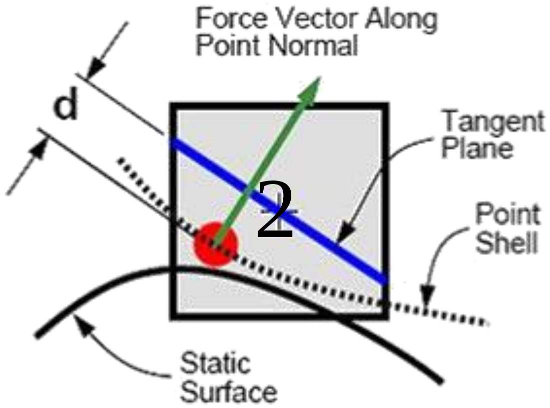


On the moving object, the center of each surface voxel is identified as a point and the set of these points creates a pointshell

The inward pointing surface normal of each point on the moving object is also identified

Tangent-Plane Force Model

When a "point" interpenetrates a surface voxel, a depth of penetration, d, is calculated.



The depth of penetration is measured from a plane that is perpendicular to the moving surface point normal and passes through the center of the static surface voxel.

The collision force and torque between the two bodies are simply modeled as springs with linear coefficients:

$$\mathbf{F}_{depth} = k_{ff}\mathbf{d}$$

$$\mathbf{T}_{depth} = k_{rr}\boldsymbol{\theta}$$

Pre-contact Braking Force

To avoid instantaneous point-voxel penetration, a braking force is added to the contact force

$$\mathbf{F}_{braking} = -b_{ff}\mathbf{v}$$

$$\mathbf{T}_{braking} = -b_{rr}\boldsymbol{\omega}$$

The pre-braking force is only applied when the objects are moving toward each other.

The total contact force is the sum of the spring contact force and the pre-braking contact force

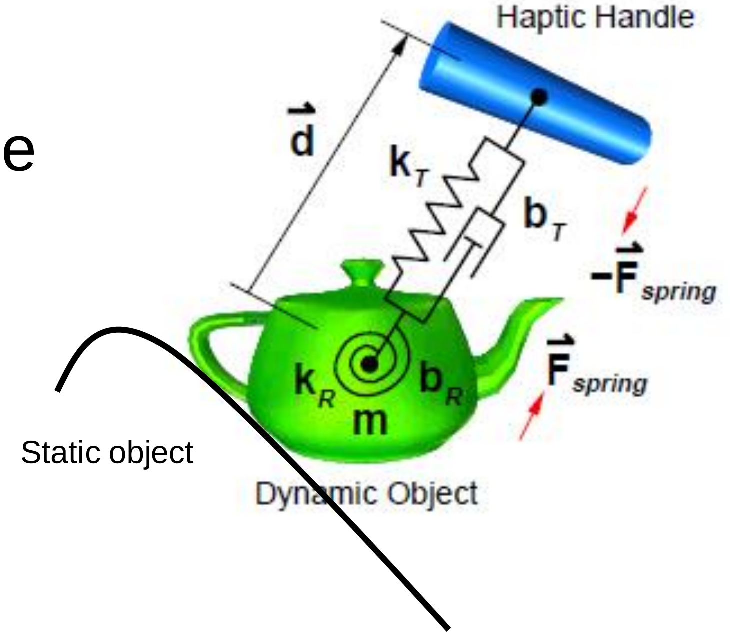
$$\boxed{\begin{aligned}\mathbf{F}_{depth} &= k_{ff}\mathbf{d} - b_{ff}\mathbf{v}\\ \mathbf{T}_{depth} &= k_{rr}\boldsymbol{\theta} - b_{rr}\boldsymbol{\omega}\end{aligned}}$$

Virtual Coupling

An additional coupling exists between the virtual haptic device (haptic handle) and the moving object

$$\mathbf{F}_{spring} = k_T \mathbf{d}_\mathbf{H} - b_T \mathbf{v}_\mathbf{H}$$

$$\mathbf{T}_{spring} = k_R \boldsymbol{\theta}_\mathbf{H} - b_R \boldsymbol{\omega}_\mathbf{H}$$



The total force sent to the haptic device is the sum of the contact force and the virtual coupling force

$$\mathbf{F}_{Total} = \sum \left(\mathbf{F}_{depth} + \mathbf{F}_{spring} \right)$$

$$\mathbf{T}_{Total} = \sum \left(\mathbf{T}_{depth} + \mathbf{T}_{spring} \right)$$

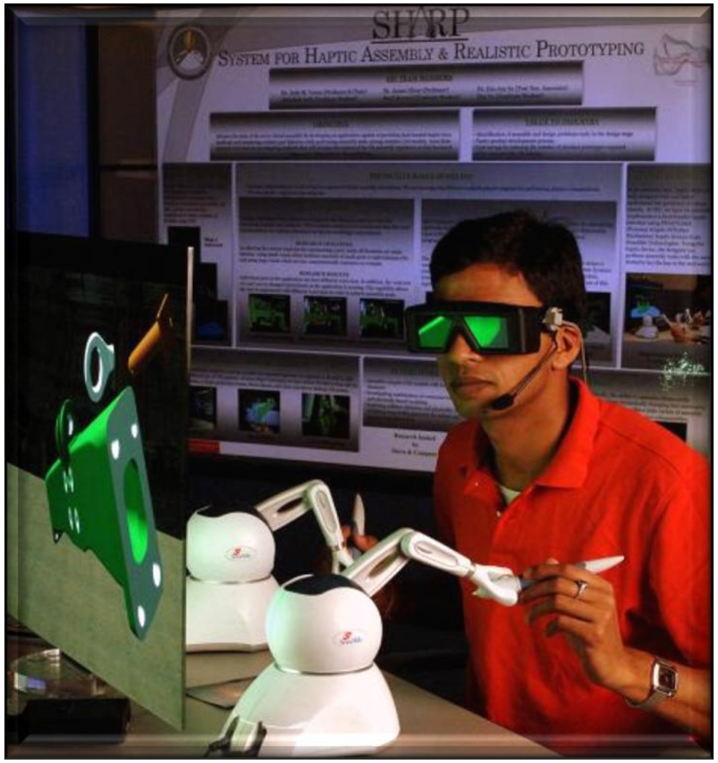
Voxmap-Pointshell (VPS) Software

- Octree voxel organization with fixed depth
- Optimizations to exploit geometrical awareness and temporal coherence
- Collision offsetting
- Pointshell shrinking
- Merged scene voxmap

SHARP

System for Haptic Assembly & Realistic Prototyping

- Physics-based modeling approach
- Collision detection
- Dual-handed haptic interface
- Complex CAD model assembly
- Subassembly support
- Swept volumes
- Network communication
- Portable to different VR Systems



Seth, A., Su, H.-J., Vance, J. M., "Development of a dual-handed haptic assembly system: SHARP", *ASME Journal of Computing and Information Sciences in Engineering*, 8(4), 2008, pp. 044502

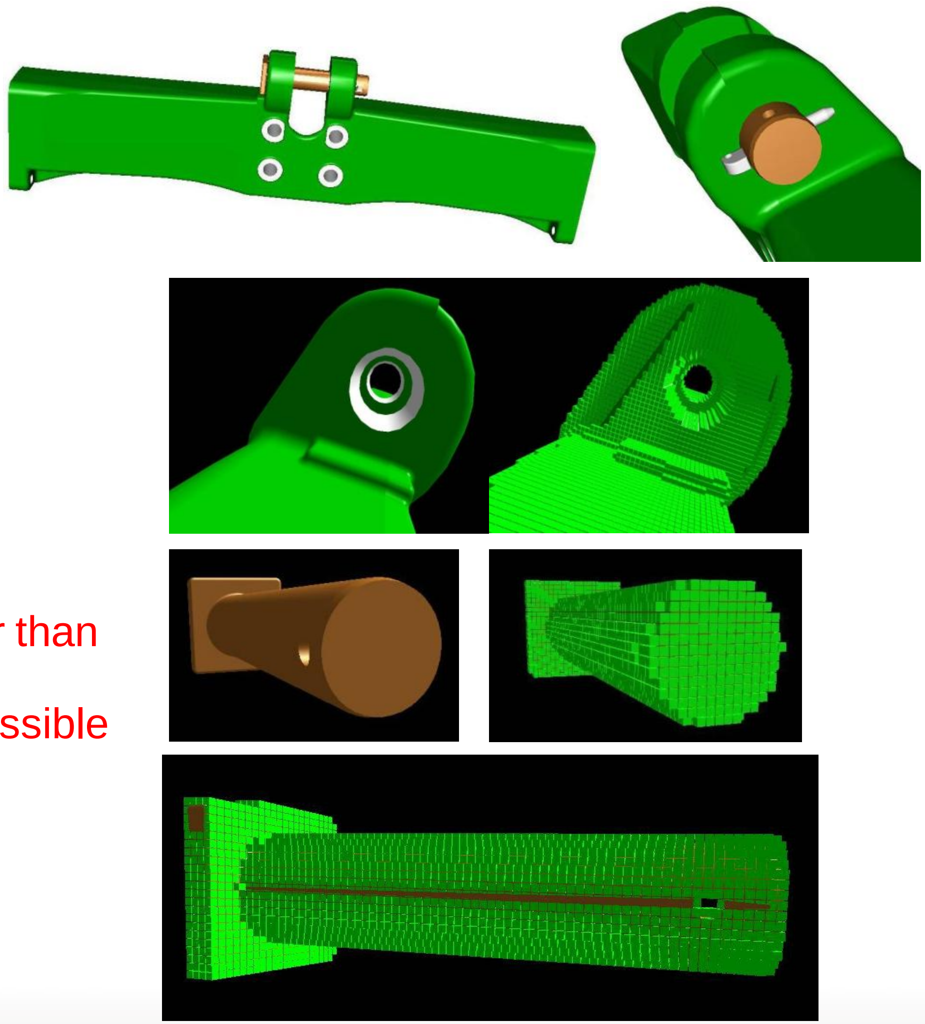
Dual-handed Haptic Assembly

SHARP

System for Haptic Assembly & Realistic Prototyping

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

- Limitations
  - Low clearance assembly not possible
  - System insensitive to features smaller than voxel size
  - Large and small part assembly not possible



Gaps in Existing Technology

Constraint-based Assembly

- Constraints need to be pre-defined
- Significant pre-processing of CAD models is required
- Positional constraints remove the user from final assembly

Physics-based Modeling

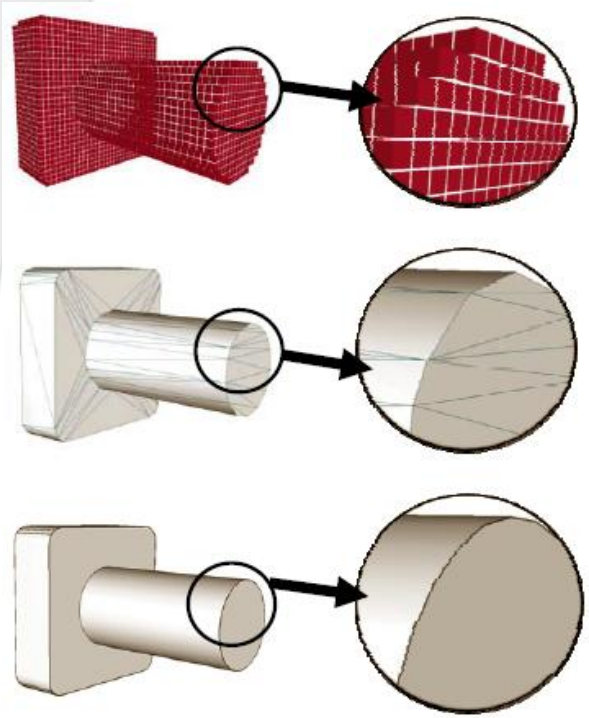
- Instability with multiple contact points
- Difficult to attain interactive update rates
- Accuracy

Combining Constraint-based Assembly with Physics-based Modeling to Support Low Clearance Virtual Manual Assembly Tasks

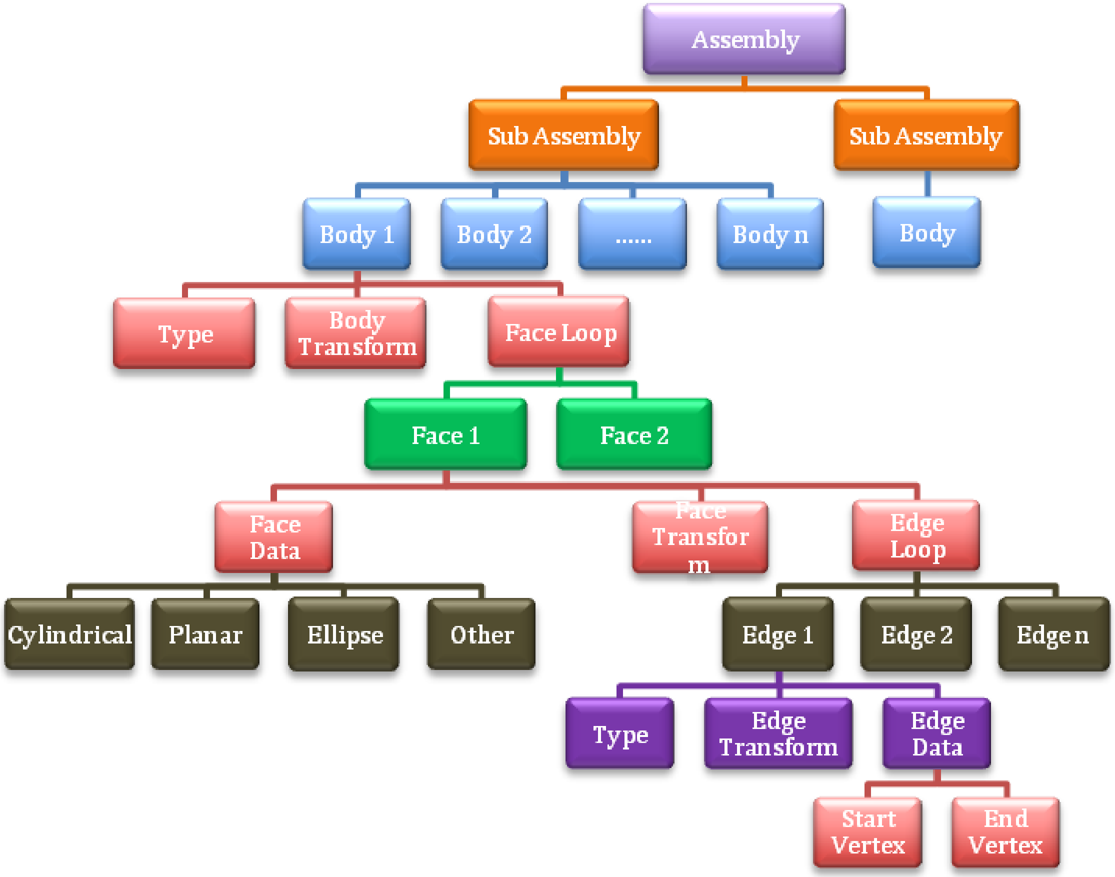
Abhishek Seth, Ph.D.

Seth, A., Vance, J. M., Oliver, J. H., "Combining dynamic modeling with geometric constraint management to support low clearance virtual manual assembly tasks," *ASME Journal of Mechanical Design*, 2010, in press.

Move to B-Rep Data Model

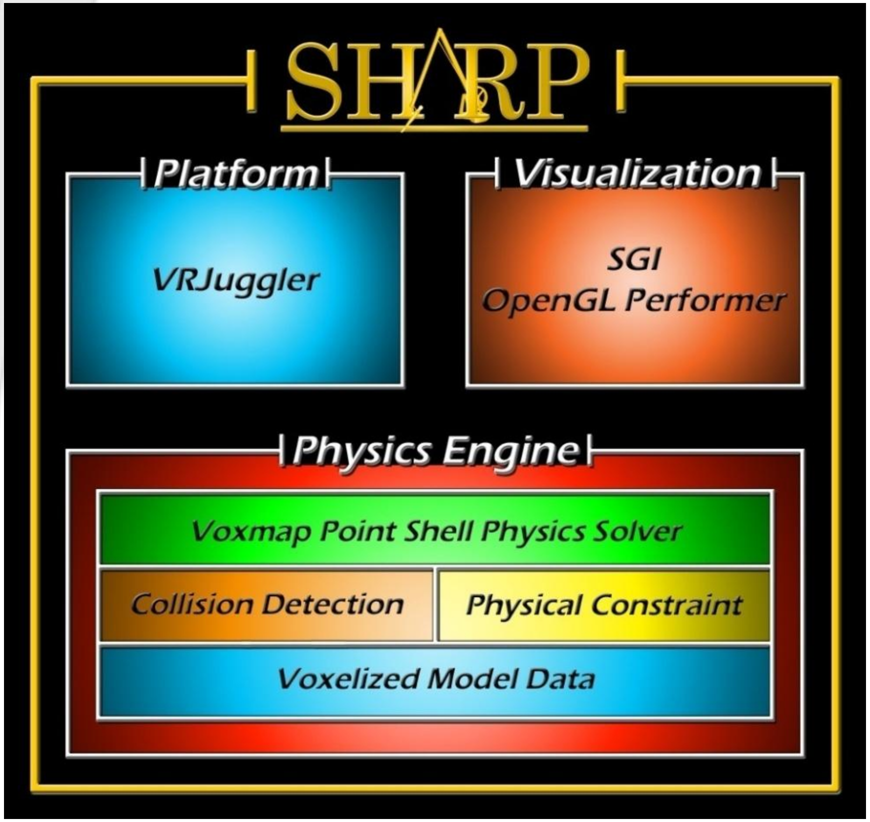


Voxel, tri-mesh and B-Rep representations of a model

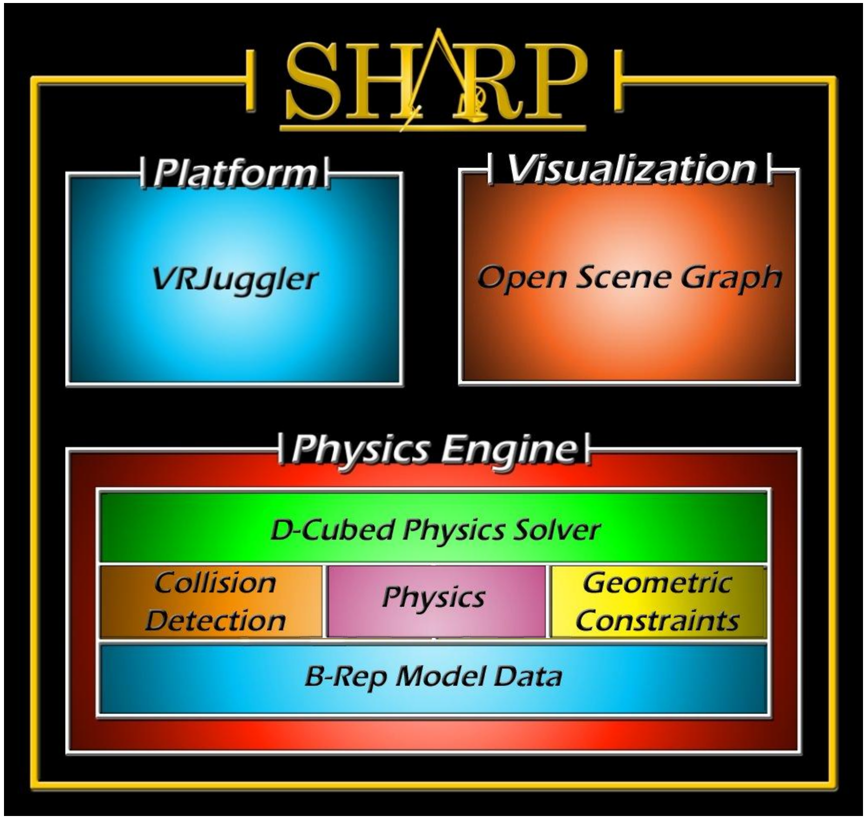


B-Rep Structure in an .X_T Assembly file

OLD

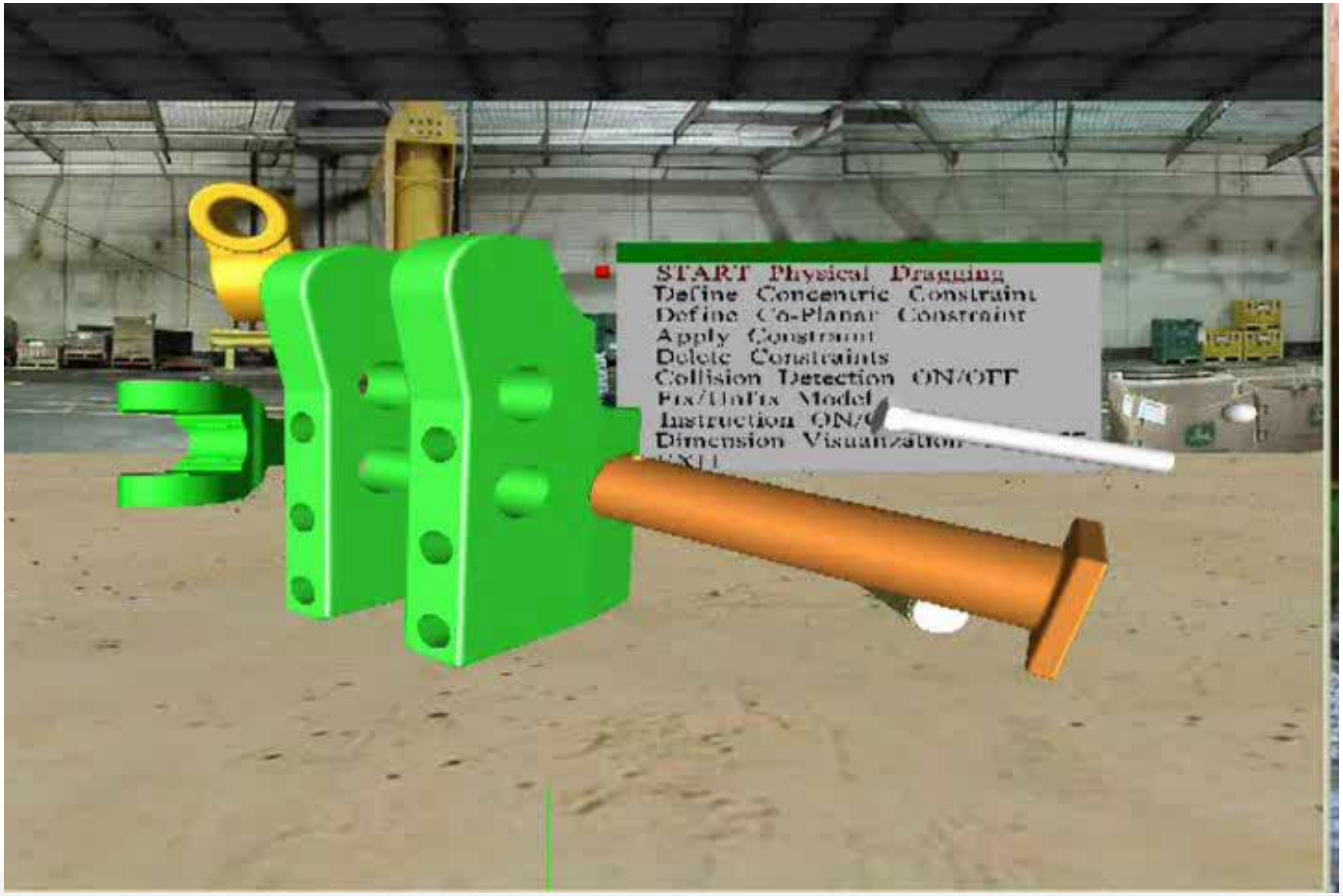

SHARP
Platform
Visualization
VRJuggler
SGI
OpenGL Performer
Physics Engine
Voxmap Point Shell Physics Solver
Collision Detection
Physical Constraint
Voxelized Model Data

NEW


SHARP
Platform
Visualization
VRJuggler
Open Scene Graph
Physics Engine
D-Cubed Physics Solver
Collision Detection
Physics
Geometric Constraints
B-Rep Model Data

Low Clearance Assembly

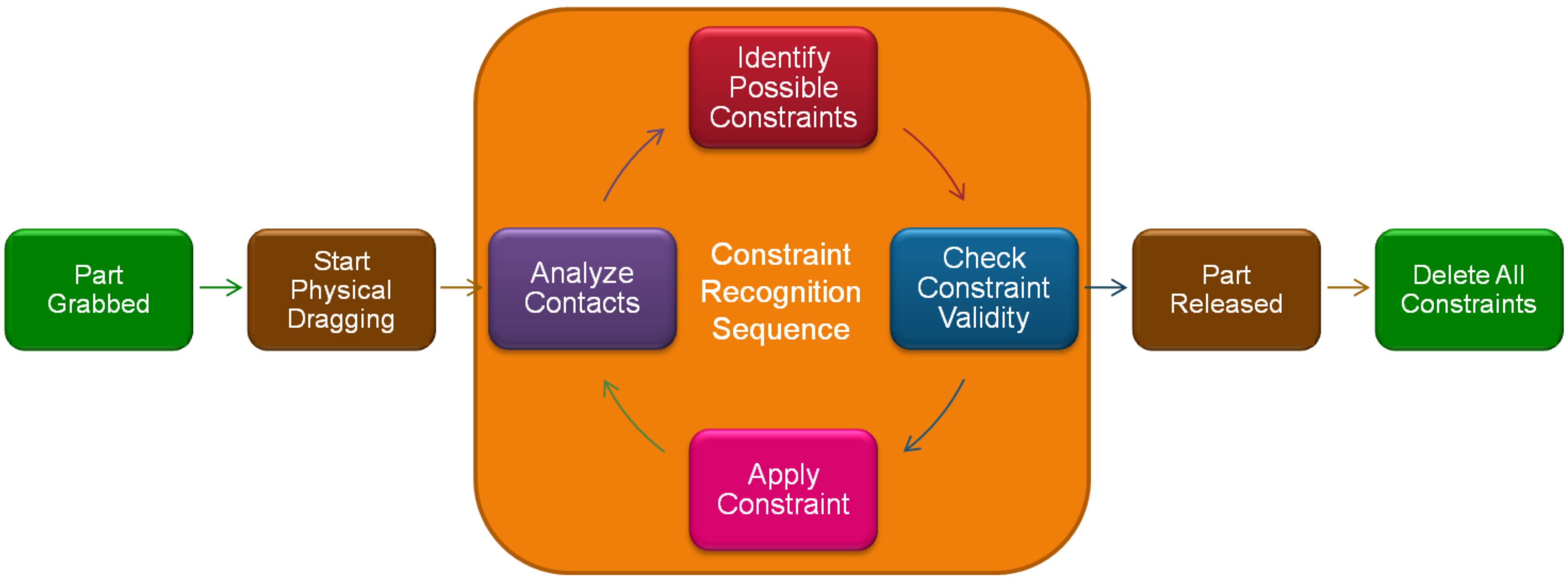
Collision, Physics-based Modeling, Geometric Constraints



Automatic Constraint Recognition

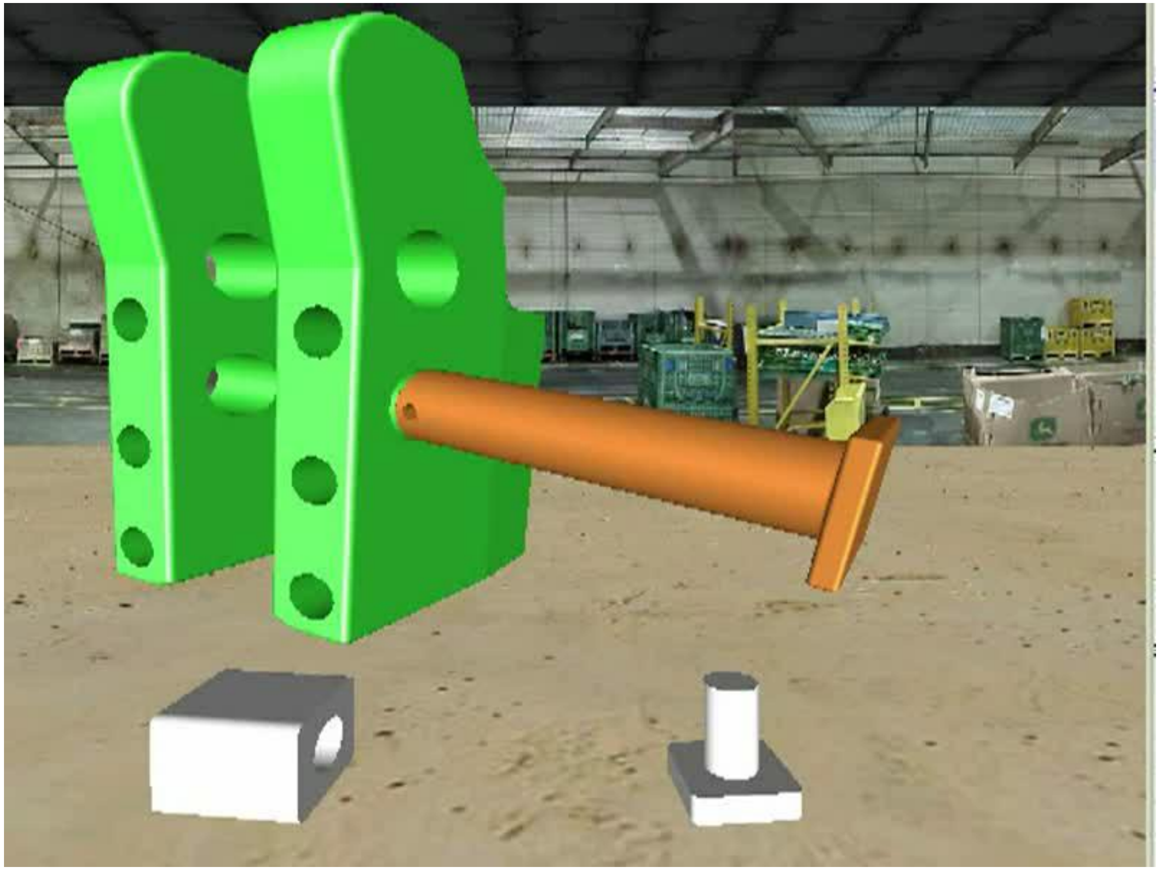
Feature-based approach

- Monitors exact contacting geometries (faces/edges) during assembly to predict user's assembly intent
- Identifies, adds and deletes geometric constraints automatically



Low Clearance Assembly

Collision, Physics-based Modeling, Automatic Constraints

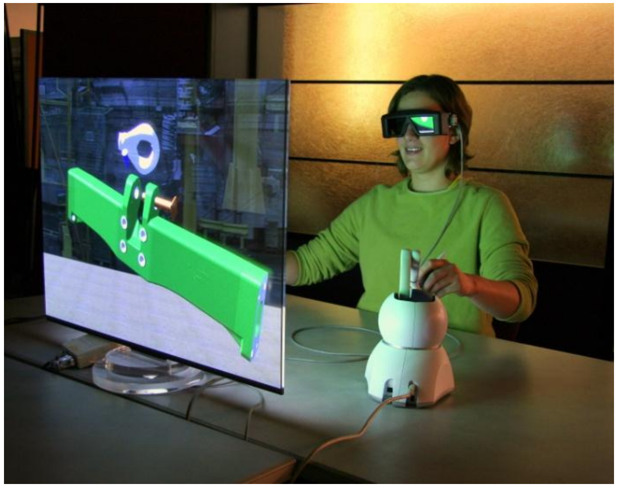


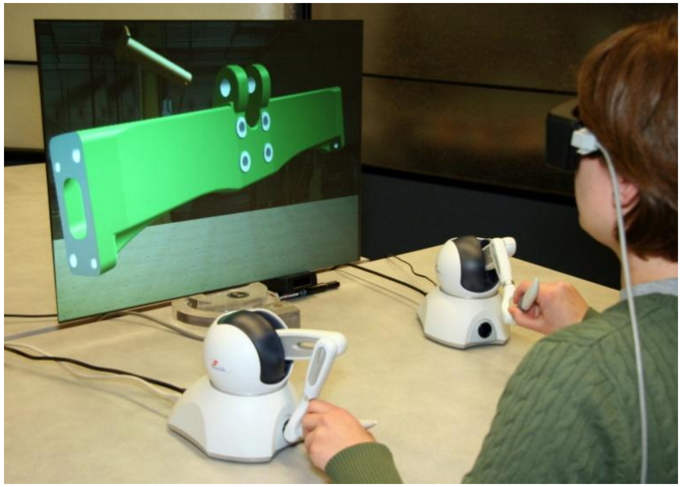
Summary

- **Advantages**
  - Low clearance assembly possible
  - Direct data transfer from CAD - VR
  - Runtime definition of geometric and physical constraints
  - Feature-based automatic constraint recognition
  - Realistic part behavior
  - Support for different VR systems
  - Ability to handle arbitrary CAD data
  - Intuitive user interaction
- **Disadvantages**
  - Poor system performance when handling large assemblies
  - No haptic interaction enabled
  - Tied to proprietary software (Siemens D-cubed) for constraint recognition

A Hybrid Method of Haptic Feedback to Support Virtual Manual Product Assembly

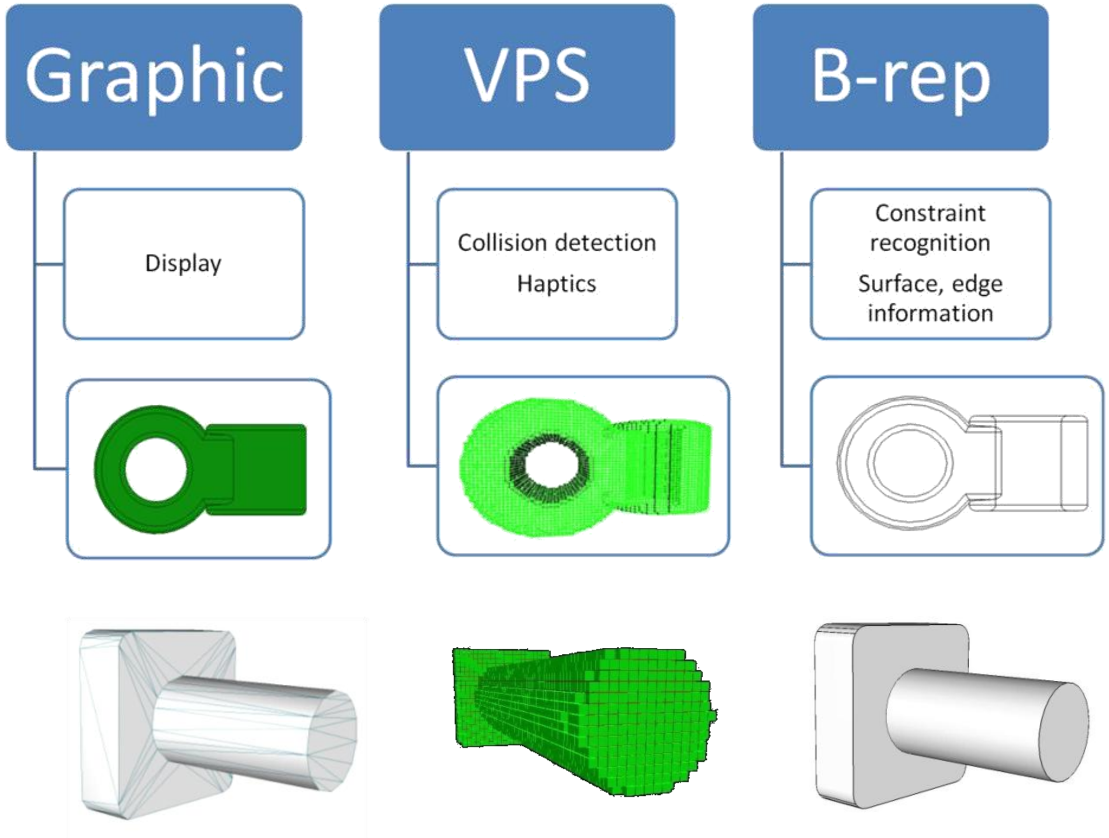
Develop and evaluate a new hybrid method of collision detection and haptic modeling that will more realistically simulate natural interaction of low clearance parts in a virtual environment.





Daniela Faas, Ph.D. Candidate

Multiple Geometric Representations



Asymmetric Interfaces for Bimanual Virtual Assembly with Haptics

Patrick Carlson, PhD Candidate
Vikram Vyawahare, PhD Candidate

Motivation

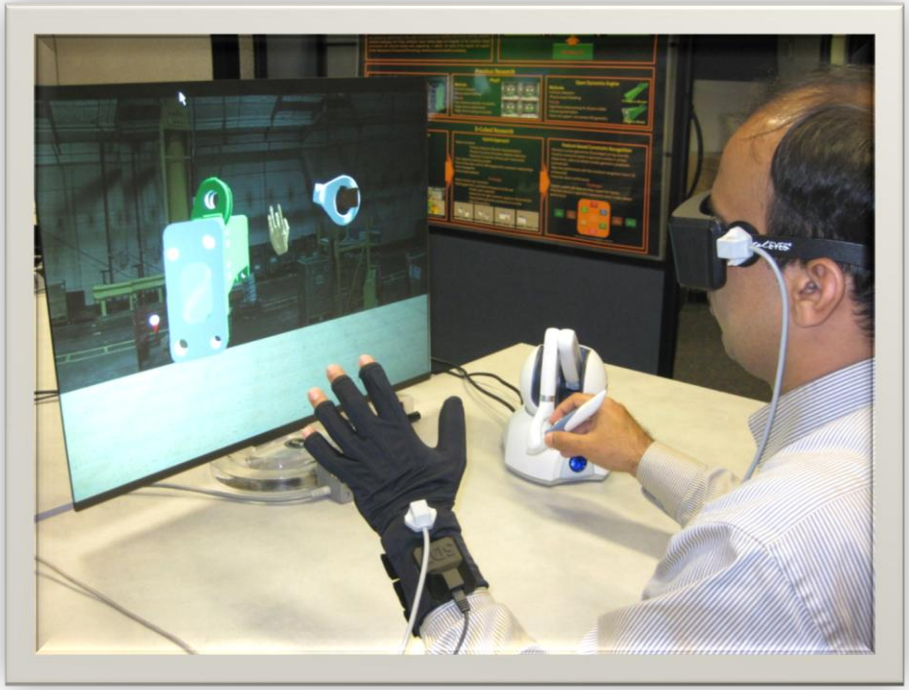
Research has shown that we naturally use our "non-dominant hand" to select and manipulate objects while we use our "dominant hand" to perform fine motor skill movements.

Combining the glove (large workspace) with the haptic device (small workspace) will allow us to select and manipulate objects in a large area of the virtual environment and also support haptic assembly.

Approach

Use a non-haptic glove on the non-dominant hand

Provide a haptic device for interaction with the dominant hand



Vyawahare, V. S., Vance, J. M., "Human centered multimodal 3D user interface for desktop VR assembly", *Emerging Technologies Conference (ETC) 2009*, Apr 2-3, 2009, Ames, IA, ETC-2009-0031.

User Study

Hardware

- Two Phantom Omnis from Sensable
- 5DT Data Glove
- Patriot Tracker from Polhemus
- 120 Hz projector display for stereo
- Crystal Eyes active stereo glasses

Software

- VRJuggler
- Voxmap Pointshell (VPS) for collision detection and force calculations

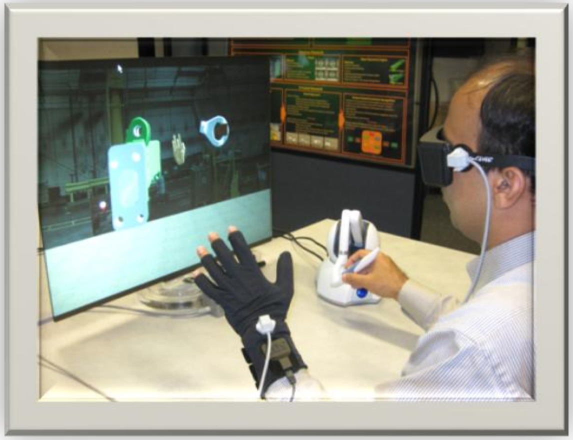
User Study Variables

Dependent Variable

- Time taken for task

Independent Variables

- Device Configuration
  - Haptic - Haptic
  - Nonhaptic – Haptic
  - Glove - Haptic
- Hand (dominant / nondominant)
- Task (simple / hard)



Research Approach

	Haptic-Haptic (Omni-Omni)	Nonhaptic-Haptic (Omni-Omni)	Glove-Haptic (Glove-Omni)
Simple Task		Nonhaptic in dominant hand Nonhaptic in nondominant hand	Glove in dominant hand Glove in nondominant hand
Hard Task		Nonhaptic in dominant hand Nonhaptic in nondominant hand	Glove in dominant hand Glove in nondominant hand

Removing haptic ability from one hand does not result in decreased performance compared to haptic enabled devices in both hands.

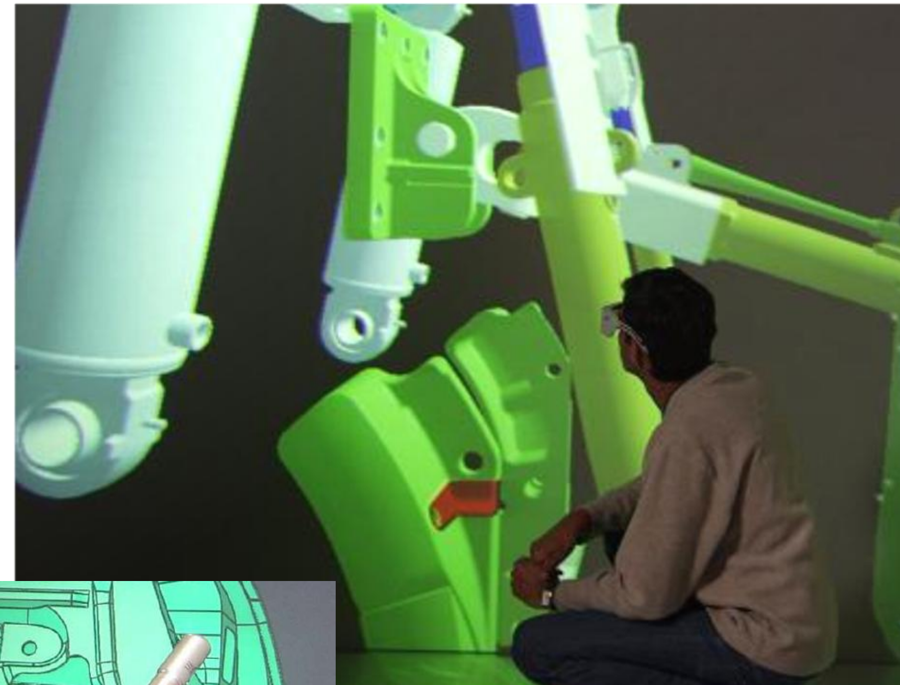
The use of the glove in the non-dominant hand and the haptic device in the dominant hand positively affects performance compared to haptic device in the non-dominant hand and glove in the dominant hand.

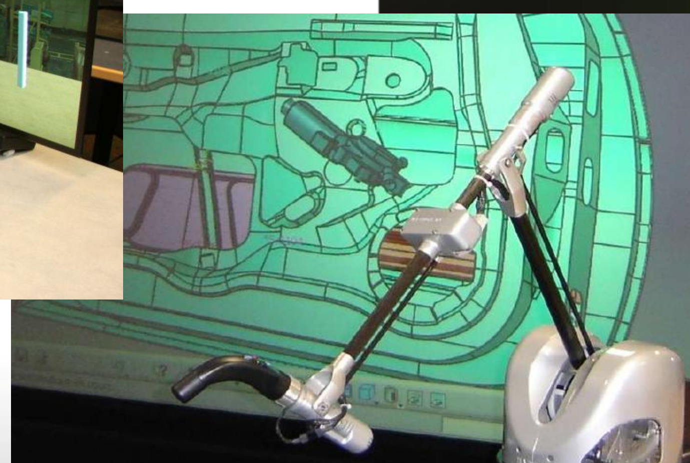
User Centered Haptics for Virtual Assembly

Vikram Vyawahare, Ph.D. Candidate

Putting it all together

- Low clearance assembly
- Bimanual interaction
- Haptics for large work areas





Human Scale Haptics

Combine

- Haption Virtuose 6D35-45
- Mobile platform
- 5DT data glove

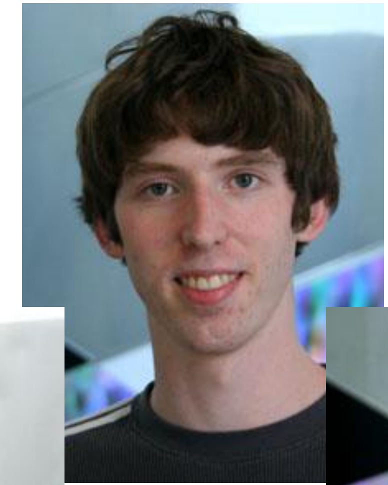
Implement in a large scale projection screen environment

Research and Teaching Plans

- Interdisciplinary design education
- Use of VR to aid mechanical engineering
- VR in the classroom
- Integration of haptics with visual and audio

Acknowledgements





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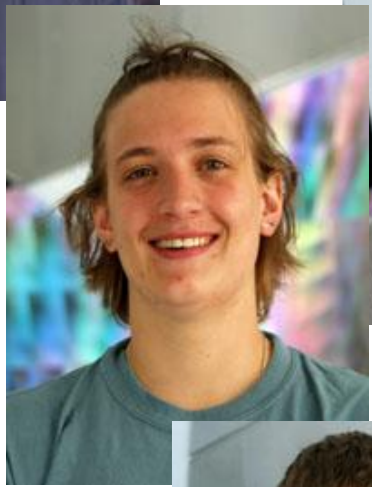





JOHN DEERE
Human Computer Interaction
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

ASME

HOME SEARCH JOIN SHOP HELP

WINVR 10

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About the Conference

The **ASME 2010 World Conference on Innovative Virtual Reality (WINVR2010)** will be held from May 12-14, 2010 in Ames, Iowa. The conference will bring together international leaders from academia and industry to discuss current research and practice in the use of virtual reality to solve industrial problems. WinVR is partnering with the VIRMAN (Virtual Manufacturing) Workshop, and the ETC (Emerging Technologies Conference) to provide a venue for discussion and sharing that crosses disciplinary boundaries. This conference builds on the previous success of WinVR09, VIRMAN'08 and ETC09.

Technical Tracks

The conference conference seeks original high quality papers in all areas of virtual, mixed and augmented reality and will be accepting submissions to the following technical tracks:

- TRK 1: Virtual Reality Applications
- TRK 2: Product Design & Manufacturing
- TRK 3: User Interfaces & Human-Computer Interaction

For more information, view the track descriptions.

www.asmeconferences.org/WINVR2010