Virtual Reality for Planning and Controlling of Robot-based Servicing in Space

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Knowledge for Tomorrow

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German Aerospace Center

- Germany's national research center for aeronautics and space
  - Exploration of the Earth and the Solar system
  - Research for preservation of the environment
  - Research for mobility and public safety
  - Addressing societal questions on behalf of public customers
- Germany's space administration
  - Responsible for the forward planning and the implementation of the German space program by the German federal government
- Germany's largest project management agency

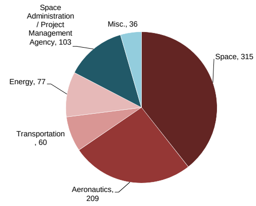

Fig.: Total income 2013 (Mio. €)

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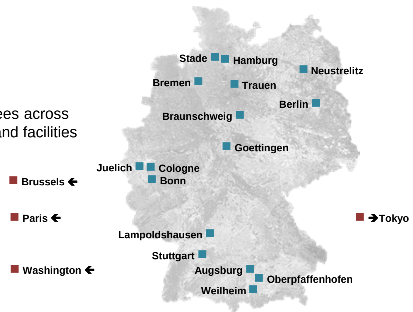
German Aerospace Center

- Locations
  - 16 Sites
  - 4 Offices
- Employees
  - 7400 employees across 32 institutes and facilities



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Virtual Reality

Virtual Reality in DLR Applications
(Just an Excerpt)

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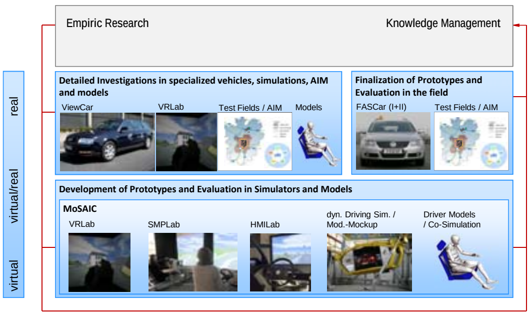
Virtual Reality at DLR
Institute of Transportation Systems



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Virtual Reality at DLR
Institute of Aerodynamics and Flow Technology

- In-Door Airflow
  - Themal Passenger Confort as crucial Design Criterion for Air Condition and Equipment for Air and Train Cabins

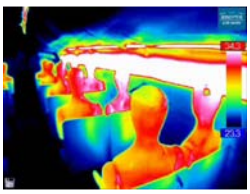

Fig.: Surface Area Thermography Imagery of an Airbus A380 Cabin Mock-Up

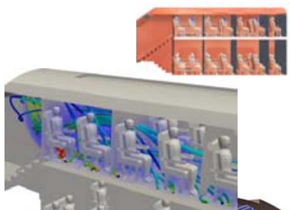

Fig.: Air Flow Simulation in a Train Cabin; Surface Visualization (top), Particle Tracing (mid), Topology Extraction and Visualization (bottom)

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Virtual Reality at DLR
Institute of Planetary Research

- Planetary Geology / Geodesy
- Remote-sensing experiments
  - High Resolution Stereo Camera (HRSC)
  - Mars Express Mission
    - Launch: Juni 02, 2003

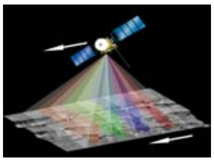

Fig.: High-Resolution Stereo Camera (HRSC), Push-Broom Scanner

Video: Interactive Mars Exploration

- Scientific Goal:
  - Investigation of Atmosphere, Volcano Activities, Water Reservoirs, and Morphological Processes over the Evolution History of Mars

Virtual Reality at DLR
Institute of Robotics and Mechatronics

- Astronaut Training
- Spacecraft Design
  - On-Orbit Simulations
- Satellite Operation
  - On-Orbit Servicing

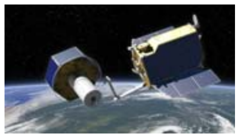

Fig.: DEOS – Rendezvous and Docking for Orbital Servicing Missions

Fig.: International Space Station

Fig.: On-orbit Satellite Servicing (OOS)

Virtual Reality Assembly Simulation

Virtual Reality Assembly Simulation
Motivation

- Physical Evaluation Mock-up

Fig.: Tele-Presence System demonstrated at ILA 2010 in Berlin

Virtual Reality Assembly Simulation
Motivation

- From physical to virtual mock-ups

Fig.: Tele-Presence System demonstrated at ILA 2010 in Berlin

Virtual Reality Assembly Simulation
Servicing Tasks

- Remove Multi-Layer Insulation (MLI)
- Take Measurements (e.g. using a Voltmeter)
- Operate Switches
- Loosen / Tighten Screws
- Remove / Insert Modules (e.g. using a Bayonet Handle)

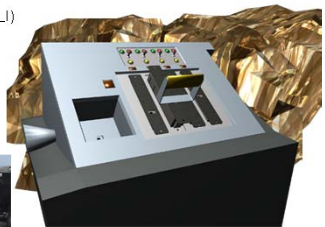

Fig.: Virtual Satellite Mock-up

Fig.: Physical Satellite Mock-up

- EVA Task Sheet
  - Step-by-Step Work Activity Instruction for Astronauts

Virtual Reality Assembly Simulation
Systems Requirements

- Interactive Real-Time Simulation
- Fast Response Times necessary
- Complexity vs. Accuracy Trade-off
- Dedicated Machines used for Computation

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Virtual Reality Assembly Simulation

Physics Engines

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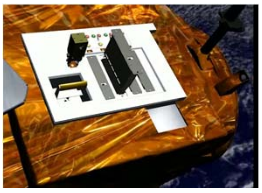
Physics Engines
Requirements and Constraints

- In Use: Bullet Physics Engine
  - Real-Time n-Body Simulation
  - Support for Rigid Bodies
  - Simplified Collision Detection
  - Universal Constraints
  - Support for Soft Bodies
  - Optimized for Speed, rather than Accuracy



What's about alternative physics engines?

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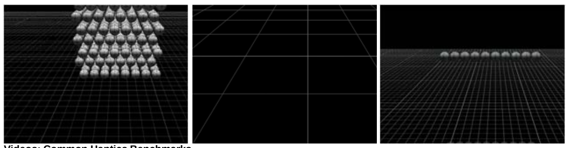
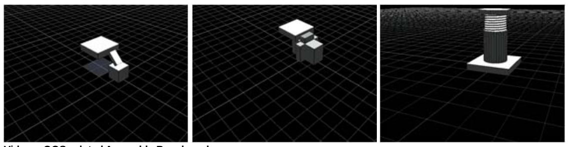
Physics Engines
Benchmarks for Open Source Physics Engines



Videos: Common Haptics Benchmarks



Videos: OOS-related Assembly Benchmarks

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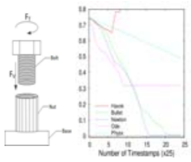
Physics Engines
Benchmarks Results

- Assessed Physics Engines:

Bullet, havok, newton, ODE, PhysX by NVIDIA

- Six Benchmarks measured:
  - Performance of Collision Computations
  - Preservation of Energy
  - Constraint Reliability
  - Inter-penetration
  - Computation of Collision and Friction for complex Compound Objects



- Results:
  - No Physics Engine performed best for any given Task
  - Nvidia PhysX fits best for VR-OOS

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Virtual Reality Assembly Simulation

Haptic Rendering

Voxelmap-Pointshell (VPS)

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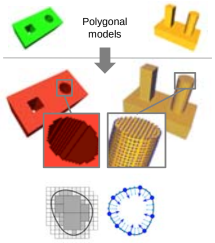
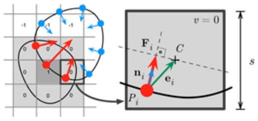
Voxmap-Pointshell (VPS) Algorithm
Principles

Data Structure Generation (Offline ~1 sec.)



Collision Detection and Force Computation (Online <1 msec.)

1. Pointshell is transformed into Voxmap coordinates
2. Likely colliding points are checked for collision
3. Normal vectors of colliding points are scaled with local and global penetration in the Voxmap yielding single collision forces



$$\mathbf{F}_i = \max\{\underbrace{\mathbf{n}_i\mathbf{e}_i}_{\text{local}} + \underbrace{vs}_{\text{global}}, 0\}\mathbf{n}_i \rightarrow \mathbf{F}_{tot} = \sum_{\forall i | v(P_i) \geq 0} \mathbf{F}_i$$

$$\mathbf{T}_i = P_i \times \mathbf{F}_i \rightarrow \mathbf{T}_{tot} = \sum_{\forall i | v(P_i) \geq 0} \mathbf{T}_i$$

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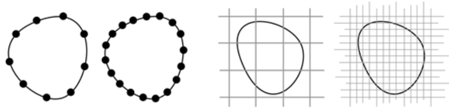
Voxmap-Pointshell (VPS) Algorithm
Level-of-Detail Accurate Collision Detection

Pointshells strongly influence the quality of the force **direction and the computation time**

Voxmaps strongly influence the quality of the force **magnitude**



Point-Sphere Hierarchy

Interpolation with Distance Fields

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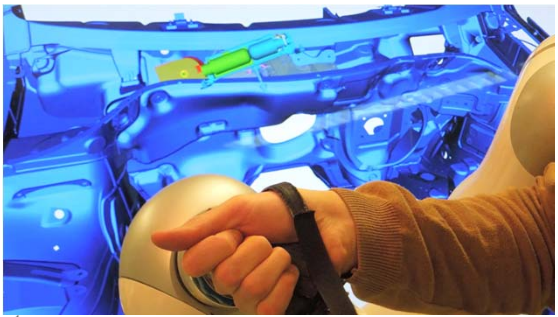
Voxmap-Pointshell (VPS) Algorithm
Complex Virtual Car Assembly Simulation



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Virtual Reality Assembly Simulation

Finger Tracking

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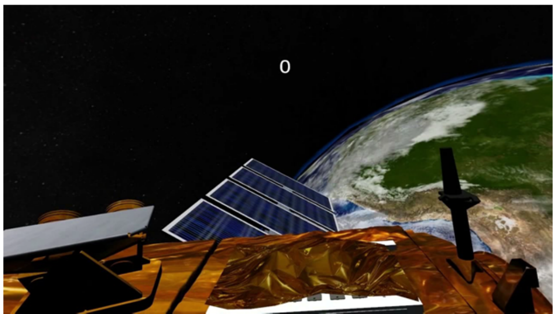
Finger Tracking
Different Input Devices for Grasping



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Heaviness Representation in Virtual Environments
Distance Based Method

- Tracking
  - 5-finger finger tracking device
    - Available by A.R.T.
- Mapping
  - Penetration / Finger distance
- Feedback
  - Kinesthetic and proprioceptive
  - Visual

Real World

Virtual World

Method 1: Finger Distance

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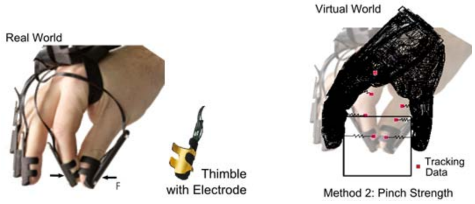
Heaviness Representation in Virtual Environments
Pinch Based Method

- Tracking
  - 5-finger finger tracking device
    - **Prototype** by A.R.T.
- Mapping
  - Pinch force based
- Feedback
  - Kinesthetic and proprioceptive
  - Visual
  - **Tactile**



Method 2: Pinch Strength

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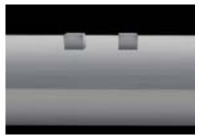
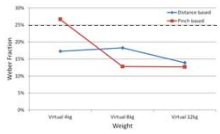
Heaviness Representation in Virtual Environments
Conclusion

- Goal:
  - Find a simple light-weight alternative to current haptic devices for immersive Virtual Reality
- Results:
  - Both methods show relative Just Noticable Difference below 20%
    - ➔ Applicable for VR
  - However, pinch based method not sufficient for small weights
  - On the other hand, 61% of the users preferred pinch based method





Our methods only allow to feel relative virtual weight, NOT real weight like most haptic devices do.

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Thank you for your attention.
Questions?

http://www.dlr.de/sc/vr-oos

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