Virtual Reality Applications based on Physical and Behavioral Simulation

Applied Computing Research Post-grad Program - PIPCA
UNISINOS University - Brazil
GRAPHIT - Computer Graphics and Vision Group (Unisinos/PUC-RS)
GPVA - Autonomous Vehicles Research Group (Unisinos)
GIA - Artificial Intelligence Research Group (Unisinos)
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Virtual Reality Applications based on Physical and Behavioral Simulation
Osório, Musse, Heinen, Kelber, Pessin

VI Brazilian Symposium on Computer Games and Digital Entertainment
Organized by
Unisinos
PUC-RS

Conference Chairs
Soraia Musse
Fernando Osório
Christian Hofsetz
João Ricardo Bittencourt
Luiz Gonzaga Jr.

Presentation Topics

Agenda:

1. Introduction: VR - Hierarchy of Models
2. VR and Simulation
   Geometry, Physics, Behaviour, Knowledge and Cognition
3. Physics Simulation Tools
   Opensteer, ODE, PhysX, Deformable/Dynamic
4. Intelligent Behaviour
   Agents: Perception, Action, Behaviour
   Autonomous Agents - Control
5. Multi-Agents Systems - Knowledge
6. Applications: VR Simulation Tools
7. Conclusions and New Trends
Virtual Reality

Introduction VR - Virtual Reality

From REAL to VIRTUAL
3D + Immersion + Interaction
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IEEE Computer Chapter - Colombia Section / Medellín, July 2007

Virtual Reality

Introduction VR - Virtual Reality

3D Visualization

3D World Recreated:

3D Coordinate System - Axes X, Y, Z

- Create 3D objects
  - Position, Scale, Orientation
  - Color, Texture, Light
  - Mesh of polygons (faces = polygons)

- "Virtual camera"

Labirinto

Castle
Introduction VR - Virtual Reality

Virtual Reality...

* VRML - 3D Worlds (Geometry)
* QTVR - Panorama 3D (Images)
Augmented Reality

Real World Integrated with Virtual Objects

ARTool Kit

Figure 4: The Vision-Based AR Tracking Process
http://www.hitl.washington.edu/artoolkit/

Augmented Reality: ARToolkit - Positioning 3D Objects using references obtained with a camera (webcam)

\`ARToolKit2.65vrml\`bin
simpleVRML.exe
simple.exe
Augmented Reality

Real World Integrated with Virtual Objects

Virtual Reality

VISUALIZING 3D & VIRTUAL ENVIRONMENTS

Virtual Reality...

* 3D Virtual Environment
* Interaction
* Immersion
* Realism
Virtual Reality

VISUALIZING 3D & VIRTUAL ENVIRONMENTS

Virtual Reality...

* 3D Virtual Environment
* Interaction => Virtual Reality Devices
* Immersion => Virtual Reality Devices
* Realism => Graphical Realism (photo-realism)
  Movements
  Interaction Real x Virtual
  "Physics Realism"

How to do it?
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

![Hierarchy of Models Diagram](image)

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Cognitive Modeling

Behavioral

Physical

Kinematic

Geometric

[Phunge 1999]

Sources of Inspiration:

Phantom

Haption

Omega

CyberForce

[Phunge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Cognitive Modeling]

[Behavioral]

[Physical]

[Kinematic]

[Geometric]

Agents

[Ari Chapiro - Dance]

[Funge 1999]

[CromosLab]

The Sony Dream Robot simulated into Worlds

The Sony Dream Robot in the real world

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Virtual World

Real World

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2. VR and Simulation

Sources of Inspiration:
Presentation Topics

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Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Image of a pyramid showing the hierarchy of models: Geometric, Kinematic, Physical, Behavioral, Cognitive, Modeling, Virtual World, Real World.]

Increasing Reality in VR Applications: Physical and Behavioral Simulation

[Image with the title “2. VR and Simulation” and a diagram showing the hierarchy of models.]
3. Physics Simulation Tools

Simulation Tools:

1. OpenSteer

2. ODE - Open Dynamics Engine

3. PhysX AGEIA

4. Deformable Objects and Fluids:
   - Finite Elements Methods
   - Spring-Mass Systems
   - CFD (Computational Fluid Dynamics)
   - Level Set Methods

VR Simulation: Some important questions...

Physics:
- Physical structure: resistance, mass, density, elasticity;
- Position and orientation in the 3D space;
- Kinematics and Dynamics;
- Linear and angular velocities;
- Motion (w/ forces and torques), trajectories;
- Acceleration, deceleration;
- Attraction and repulsion;
- Gravity, friction, inertia;
- Kinetic and potential energy;
- Laws of energy conservation, linear and angular momentum;
- Collisions and reaction to collisions;
- Steering models (wheeled cars, aircrafts, projectiles, boats and ships);
- Articulated Rigid Bodies Simulation (skeleton, robotic arm);
- Dynamic Simulation of Deformable Objects: elastic objects;
- Fluid simulation and Particle Systems (fire, smoke, clouds and liquids).
3. Physics Simulation Tools

1. OpenSteer [Reynolds]

Simple steering behaviours

- Flee path
- Current velocity
- Seek path
- Desired velocity (flee)
- Desired velocity (seek)
- Target

Steering Behaviour
Group Behaviour

Geometric: Simple
Kinematic: Simple
Physical: Simple
Behavioural: Simple

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2. ODE - Open Dynamics Engine

Simulation of Articulated Rigid Body Dynamics

Open Source Library (C/C++ API)

Used with OSG, Ogre3D, CrystalSpace, ...

3. Physics Simulation Tools

Physics Simulation:

- Gravity, friction, acceleration, deceleration;
- Generation of motion: applying forces and torques (motors);
- Collision avoidance and treatment (reaction, object bounce);
- Kinematics models and rigid body dynamics simulation;
- Different types of joints with actuators (motors)
3. Physics Simulation Tools

2. ODE - Open Dynamics Engine
3. Physics Simulation Tools

2. ODE - Open Dynamics Engine
3. Physics Simulation Tools

2. ODE - Open Dynamics Engine

Webots
Cyberbotics

26 July 2007
3. Physics Simulation Tools

3. PhysX AGEIA

Hardware Accelerated Physics Simulation

PPU - Physics Processing Unit / GPU - Graphics Proc. Unit

- Complex rigid body object physics system: dynamics and collision detection
- Joints and springs. Characters with complex, jointed geometries for more lifelike motion and interaction
- Volumetric fluid creation and simulation
- Cloth that drapes and tears the way you would expect it to
- Smart particles. Dense smoke and fog that billow around objects in motion.
- Explosions that cause dust and collateral debris

Screenshots of the AGEIA PhysX effects [AGEIA 2006]

3. Physics Simulation Tools

Simulation Tools:

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VR Simulation: Some important questions...
3. Physics Simulation Tools

4. Deformable Objects and Fluids
- CFD
  Computational Fluid Dynamics
- Level Set Methods

[Fedkiw 2006]
3. Physics Simulation Tools

Simulation Tools:

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   - Finite Elements Methods
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   - Level Set Methods

VR Simulation: Some important questions...
REAL TIME SIMULATION!

4. Intelligent Behaviour

Intelligent Agents:

Agents: Perception, Action
Agent Behaviours
Control Architectures
Autonomous Agents
Multi-Agents Systems
Knowledge / Reasoning

Agent

Perceber → Decidir → Agir

Arquitetura puramente reativa
4. Intelligent Behaviour

Intelligent Agents:

Agents: Perception, Action
Agent Behaviours

Control Architectures
Autonomous Agents → Robotic [GPVA]
Multi-Agents Systems → Crowds [CromosLab]
Knowledge / Reasoning → Ontology [GIA]
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6. Conclusions and New Trends

5. Applications: VR Simulation Tools

Applications @ Unisinos

1. Autonomous Robots in VR Environments
   SimRob3D - Mobile Robots Simulator
   SEVA 3D - Autonomous Vehicle Parking
   LEGGEN - Legged (articulated) Robots Simulator

2. Knowledge and Reasoning in VR Environments
   UEM - Urban Environment Model
   Crowds Simulation in Normal Life Situations
   Robombeiros - Fire Fighting
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SimRob3D

- Our Simulation Tools:
  - SimRob2D (Khepera)
  - SimRob3D
  - Seva2D

SimRob3D Simulator

> Sensors: Infrared, Sonar, Bumper

> Actuators / Kinematics: Differential, Ackerman

> Realistic Simulation Model:
  3D World + noise / error (imprecise sensors and actuators)

\[
\begin{align*}
    \dot{x} &= v \cos \phi \cos \theta \\
    \dot{y} &= v \cos \phi \sin \theta \\
    \dot{\theta} &= \frac{v}{l} \sin \phi
\end{align*}
\]
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SimRob3D Simulator

- Vehicle Simulation
- Vehicle Control

SimRob3D

- Kinematics: Estimation of Position and Orientation
- Perception: Sensor Simulation
- Motor Actions
- Sensorial Information

Visualization

HyCAR

- Hybrid Control of Autonomous Robots

Commands

Sensors

3D World

Robot Model

Autonomous Robots in VR Environments
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SEVA 3D - "Sistema de Estacionamento de Veículos Autônomos"

Sources of Inspiration:

- Baja Buggy remotely controlled by a cell phone
  C. Kelber - UNISINOS, Brazil

Published at:
IEEE WCCI
IJCNN 2006

SEVA3D: Using Artificial Neural Networks to Autonomous Vehicle Parking Control

Applied Computing Research Post-grad Program - PIPCA
Autonomous Vehicles Research Group
[Grupo de Pesquisas em Veículos Autônomos - GPVA]
UNISINOS University - Brazil

Web: http://inf.unisinos.br/~osorio/seva3d
or Google: veículos autônomos

IEEE WCCI - IJCNN 2006
Vancouver, July 2006

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5. Applications: SEVA 3D

Autonomous Robots in VR Environments

SEVA 3D Simulator

> Vehicle Simulation

SimRob3D

Motor simulation

Kinematics:
Estimation of Position and Orientation

Perception:
Sensor Simulation

Sensorial Information

Visualization

Vehicle Control

SEVA3D

Control:
SEVA3D-A (FSA)
SEVA3D-N (Neural)

Commands

Sensors

Vehicle Simulation

SimRob3D

Motor Actions

Commands

Sensors

SEVA: FSA - Finite State Automaton

Inputs:
- Sonar Sensors:
  Stochastic ray-casting / 3D cone

Outputs:
- Steering Wheel Angle
- Gas pedal (car speed + direction: fwd, back)

States:

Automaton states
5. Applications: SEVA 3D

SEVA: Searching Parking Space

SEVA: Entering
5. Applications: SEVA 3D

**SEVA: Positioning Inside**

**SEVA: Aligning**
5. Applications: SEVA 3D

SEVA: NEURAL FSA - Learning the FSA...

Artificial neural network model scheme
Adapted Jordan-Net using RProp Learning

SEVA3D - Autonomous Vehicle Parking Simulator

3D Sensors
Actuators
Kinematics
FSA Ctrl
ANN Ctrl
5. Applications: VR Simulation Tools

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Legged Robots Evolution and Walking Control
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

Legged Robots Evolution and Walking Control

Sources of Inspiration:

LEGGEN - Published at:
IEEE WCCI CEC 2006
SBIA 2006

Gait Control Generation for Physically Based Simulated Robots using Genetic Algorithms

PIPCA Group de Pesquisas em Veículos Autônomos - GPVA
>> Autonomous Vehicles Research Group <<
UNISINOS University - Brazil

Web: http://inf.unisinos.br/~osorio/leggen
or Google: veículos autônomos

Gait Control Generation for Physically based Simulated Robots using Genetic Algorithms

IBERAMIA / SBIA / SBRN International Joint Conferences
SBIA - Brazilian Artificial Intelligence Symposium
Ribeirão Preto, October 2006

Prof. Dr. Fernando S. Osório - Applied Computing / Unisinos
Milton Roberto Heinen - Applied Computing / Unisinos
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

LEGGEN - Legged Robots Evolution and Walking Control

Simulation of Robots: 3D Realistic Virtual Environments
- **Sensors**: infrared, sonar, bumpers, gyro (accelerometers), GPS, compass, light and vision sensors, etc.
- **Actuators**: legs and arms with angular motors (joints)
- **Physics**: collision, kinematics, rigid body dynamics

Simulation of Legged Autonomous Robots:
- Robot Control Architectures Implementation

LEGGEN Simulator - Tools:

1. **OSG** - Open Scene Graph (OpenGL + Extensions)  
   [http://www.openscenegraph.org/]

2. **ODE** - Open Dynamics Engine  
   Rigid Body Physics Simulation  
   (gravity, inertia, friction, collision, joints, etc)  
   [http://www.ode.org/]

3. **GALib** - Genetic Algorithms Simulation  
   [http://www.lancet.mit.edu/ga/]

4. **Robot Control FSM**: Finite State Machine = Sense + Act
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

**LEGGEN - Legged Robots Evolution and Walking Control**

Simulation main goals:
- Evaluate different *Robot Models* (hardware configurations)
  - IEEE WCCI / CEC 2006 - Vancouver, Canada
- Evaluate different *Fitness Functions*
  - IBERAMIA / SBIA - Ribeirão Preto, SP

**Robot Models**

Evaluate different robot models in order to select a better hardware configuration

**Simulation Results:**

- Example of a generated gait (experiment 01)
- Example of a generated gait (experiment 04)
Simulation

RESULTS:

**Tetrapod Video - Distance, Gyro**
5. Applications: VR Simulation Tools

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5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

UEM - Urban Environment Model

Sources of Inspiration: CromosLab

- Normal Life - Agents: Children going to the school
  Adults going to work at usual times...

- Environment: School, Stores, ...
  Flammable Liquids...

- Ontology!
5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

**UEM - Urban Environment Model**

- Agents are created using an **ontology**;
- Ontology includes information of **population profiles**;
- Ontology includes information about the **urban environment**;
- People (virtual agents) created based on statistical data or fictitious information;
- Agents move and behave in the urban life according their usual activities (time), as described in the ontologies;
- People move during “normal life” in a more realistic way, without a “random aspect”, which is common in other (not so realistic) works;
- Able to manage crowds in a macroscopic point of view;
- Easy to define, easy to implement, easy to control!

**Knowledge about the general model of the VE can be used to the simulation:**

Structured and semantic environment

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**UEM - Global Ontology**
5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

UEM - Urban Environment Model

UEM - Global Ontology
5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

UEM - Urban Environment Model

At 7:00 AM people are at home...
5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

UEM

Urban Environment Model

At 11:29 AM:
Students and employed adults are in school and work
We can observe some other people on the street

At 12:05 PM:
Students leave school
5. Applications: VR Simulation Tools

Knowledge and Reasoning in VR Environments

UEM - Urban Environment Model

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Virtual Simulation Environment:

* 2D and 3D Simulation
* Simulation of fire propagation
* Autonomous fire-fighting team
* Define: Strategy, Mission, Execution

Fire Propagation Simulation:
- Direction and Speed of wind
- Vegetation type and coverage density (speed of propagation)
- Terrain

Published at SVR 2007 (Symposium on Virtual and Augmented Reality)

http://pessin.googlepages.com/robombeiros

[G. Pessin, F. Osório, S. Musse, V. Nonnenmacher, S. Ferreira]
**Virtual Simulation Environment:**

3D Simulation:
- Fire propagation
- Physics
- Robot Control

http://pessin.googlepages.com/robombeiros

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**Presentation Topics**

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New Trends

A 3D Fax Machine based on Claytronics

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Intel Research Pittsburgh
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Gautam Kedia, Shishir Mondal, Kaushik Sheth
Carnegie Mellon University
Pittsburgh, PA 15213

Abstract—This paper presents a novel application of modular robotic technologies. Many researchers expect manufacturing technologies will allow robot modules to be built at smaller and smaller scales, but movement and actuation are increasingly difficult as dimensions shrink. We describe an application—a 3D fax machine—which exploits inter-module communication and computation without requiring self-reconfiguration. As a result, this application may be feasible sooner than applications which depend upon modules being able to move themselves.

In our new approach to 3D faxing, a large number of sub-millimeter robot modules form an intelligent “clay” which can be reshaped via the external application of mechanical forces. This clay can act as a novel input device, using intermodule localization techniques to acquire the shape of a 3D object by casting. We describe software for such digital clay. We also describe how, when equipped with simple inter-module latches, such clay can be used as a 3D output device. Finally, we evaluate results from simulations which test how well our approach can replicate particular objects.

Fig. 1. An overview of the 3D fax scenario

VR... From Real to Virtual
Visualization (3D)
Interaction
Agents
Simulation
Conclusions => Review

VR... From Real to Virtual
Visualization (3D) => OpenGL, DirectX, VRML, QTVR, OSG
Interaction => Augmented Reality, Haptic Devices, Sensors
Agents => Behaviour (Perceive, Act, Interact), Control
Simulation => Models, Physics, ODE

* Interaction based on Physics
  Perception => Rigid Body Dynamics
  Action => Soft Body - Deformable, Particles
  Kinematics => Steering models
  Dynamics
VR... From Real to Virtual
Visualization (3D) => OpenGL, DirectX, VRML, QTVR, OSG
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* Interaction based on Physics:
  Perception Physics => Rigid Body Dynamics
  Action Soft Body - Deformable, Particles
  Kinematics Steering models
  Dynamics

* Behavioural Simulation and Virtual Autonomous Agents (AI)
  Behavioural control (e.g. boids)
  Control Architectures: Deliberative, Reactive, Hierarchical, Hybrid
  Cognitive...

Agents
- Knowledge
- Emotional states
- Personality
- Personal profile
- Special places
- Functioning rules (ontology)
- Place profile

Environment
Conclusions => Review

**Virtual Reality Applications** based on Physical and Behavioral Simulation

*Osório, Musse, Heinen, Kelber, Pessin*

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**Conclusions and New Trends**

**Virtual Reality Environments:**

Geometric + Kinematic + Physical + Behavioural + Cognitive =

Realistic RV Environments

**New Trends:**

VR
Physics
Artificial Intelligence
AR - Augmented Reality
Haptic Interfaces
Conclusions and New Trends

Virtual Reality Environments:
Geometric + Kinematic + Physical + Behavioural + Cognitive =
Realistic RV Environments

New Trends:
- VR
- Physics
- Artificial Intelligence
- AR - Augmented Reality
- Haptic Interfaces

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http://ncg.unisinos.br/robotica/

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