Autonomous robots:
Design and Testing using
Virtual Reality and Physical Simulation

Fernando Osório, Ph.D. / IEEE CS DVP

Research group:

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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IEEE Computer Society DVP Program

Jesuit University With:
- 30,000 Students
- 900 Professors
- 16 PPGs (post-grad programs)
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 Robots and Agents - Control
   Multi-Agents Systems - Knowledge
5. Applications: Autonomous Robots VR Simulation Tools
6. Conclusions and New Trends
Introduction VR - Virtual Reality

From REAL to VIRTUAL
3D + Immersion + Interaction
Virtual Reality

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

Real World Integrated with Virtual Objects

IRISA / INRIA - France
Virtual Reality...

* 3D Virtual Environment
* Interaction => Virtual Reality Devices
* Immersion => Virtual Reality Devices
* Realism => Graphical Realism (photo-realism)

How to do it?

Interaction Real x Virtual

"Physics Realism"
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](#)

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Funget 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

[Funge 1999]
1. Introduction

Sources of Inspiration:

- Phantom
- Haption
- Omega
- CyberForce

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Funge 1999]

[Ari Chapiro - Dance]

[CromosLab]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Funge 1999]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Knowledge

Autonomous Behaviour

The Sony Dream Robot simulated into Webots

The Sony Dream Robot in the real world
Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

[Funge 1999]
Presentation Topics

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Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Increasing Reality in VR Applications: Physical and Behavioral Simulation
From Simple VR Visualization Tools to Realistic VR Simulation Tools

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<th>Visualization</th>
<th>Geometry [3D Meshes]</th>
<th>Static Objects Animated Objects (Key-Frame)</th>
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<td>Simulation of Motion</td>
<td>Physics [3D Objects]</td>
<td>Rigid Body (Physically based) Kinematics (Movement)</td>
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<td>Articulations Particles (Fire, Smoke, Water)</td>
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<td>Springs (Mass-spring Systems) Deformable Objects (Cloths, Elastic, Fluids)</td>
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<td>External Forces: Interaction Interaction Object x Object Interaction Camera x Object Interaction User x Object Interactive Control</td>
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<table>
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<tr>
<th>Simulation of Behavior</th>
<th>Artificial Intelligence &quot;Simple A.I.&quot; Behavior [Agents] [Characters]</th>
<th>Agents Control Scripts Finite State Automata (FSA) Perception (Sensorial) Action (Motor) Control: Reactive Control: Deliberative Control: Modular / Hybrid Memory, Beliefs, Intentions, ... Biomechanics Simple Autonomous Agents</th>
</tr>
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</table>

Virtual World \( \times \) Real World

- Models and Components of a Virtual Reality Environment applied into Realistic Simulations
3. Physics Simulation Tools

Simulation Tools:

* ODE - Open Dynamics Engine

* OpenSteer

* PhysX AGEIA

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

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

Simulation Tools:

* ODE - Open Dynamics Engine
* OpenSteer
* PhysX AGEIA

* 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

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

Examples of Complex Deformable Objects [Fedkiw 2006]

Examples of Complex Particle Systems [Fedkiw 2006]
3. Physics Simulation Tools

* ODE - Open Dynamics Engine

Simulation of Articulated Rigid Body Dynamics
Open Source Library (C/C++ API)
Used with OSG, Ogre3D, CrystalSpace, ...

Universal joint

Ball and socket joint  Hinge joint  Slider joint
3. Physics Simulation Tools

* ODE - Open Dynamics Engine

Simulation of Articulated Rigid Body Dynamics

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

* ODE - Open Dynamics Engine
3. Physics Simulation Tools

* ODE - Open Dynamics Engine
3. Physics Simulation Tools

* ODE - Open Dynamics Engine

Webots
Cyberbotics
3. Physics Simulation Tools

* ODE - Open Dynamics Engine

Juice [Nate W.]
3. Physics Simulation Tools

Simulation Tools:

* ODE - Open Dynamics Engine
* OpenSteer
* PhysX AGEIA

* Deformable Objects and Fluids:
  - Finite Elements Methods
  - Spring-Mass Systems
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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
4. Intelligent Behaviour

**Intelligent Agents:**

**Agents: Perception, Action Agent Behaviours**

- Reactive-Deliberative Architecture
- Hybrid Architecture
- Architecture BDI (Beliefs-Desires-Intentions)
- Reactive-Deliberative Architecture

**Control Architectures:** Reactive, Deliberative, Hierarchical, Hybrid

F. Osório et al. [Virtual Concept 2005]
4. Intelligent Behaviour

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

Robotic
Teams, Squads, Swarms
Artificial Intelligence Tools
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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
   Robombeiros - Multi-Robots Fire Fighting
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SimRob3D

- Our Simulation Tools:
  - SimRob2D (Khepera)
  - SimRob3D
  - Seva2D
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

SimRob3D Simulator

> Sensors: Infrared, Sonar, Bumper

> Actuators / Kinematics: Differential, Ackerman

> Realistic Simulation Model: 3D World + noise / error (imprecise sensors and actuators)
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

**SimRob3D Simulator**
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 autonomos

IEEE WCCI - IJCNN 2006
Vancouver, July 2006

Milton Roberto Heinen - Applied Computing / Unisinos
Prof. Dr. Fernando S. Osório - Applied Computing / Unisinos
Prof. M.Sc. Farlei José Heinen - Computer Engineering / Unisinos
Prof. Dr. Christian Kelber - Electrical Engineering / Unisinos
5. Applications: SEVA 3D

Autonomous Robots in VR Environments

SEVA 3D Simulator

Vehicle Simulation × Vehicle Control

SimRob3D

Kinematics: Estimation of Position and Orientation

Perception: Sensor Simulation

Visualization

3D World

Robot Model

SEVA3D

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

Sensors

Commands

Motor Actions
5. Applications: SEVA 3D

Autonomous Robots in VR Environments

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:
SEVA: NEURAL FSA - Learning the FSA...

Artificial neural network model scheme
Adapted Jordan-Net using RProp Learning
5. Applications: SEVA 3D

SEVA3D - Autonomous Vehicle Parking Simulator

3D
Sensors
Actuators
Kinematics
FSA Ctrl
ANN Ctrl
Applications @ Unisinos

1. Autonomous Robots in VR Environments

   SimRob3D - Mobile Robots Simulator

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   ➤ LEGGEN - Legged (articulated) Robots Simulator

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5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

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
Pós-Graduação em Computação Aplicada - PIPCA
Grupo de Pesquisas em Veículos Autônomos - GPVA
>> Autonomous Vehicles Research Group <<
UNISINOS University - Brazil

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

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

Genetic Evolved Control of Articulated Robots (w/legs)
5. Applications: VR Simulation Tools

Autonomous Robots in VR Environments

LEGGEN - Legged Robots Evolution and Walking Control

Simulation of 3D Realistic Virtual Legged Robots

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_
Simulation RESULTS: *Tetrapod Video - "bloopers"*
Applications @ Unisinos

1. Autonomous Robots in VR Environments

   SimRob3D - Mobile Robots Simulator

   SEVA 3D - Autonomous Vehicle Parking

   LEGGEN - Legged (articulated) Robots Simulator

   Robombeiros - Fire Fighting
Robombeiros - Fire Fighting VR Simulation

**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

Figure: 2D Simulation using SDL library => http://pessin.googlepages.com/robombeiros

Published at SVR 2007 (Symposium on Virtual and Augmented Reality)
[G. Pessin, F. Osório, S. Musse, V. Nonnenmacher, S. Ferreira]
Robombeiros - Fire Fighting VR Simulation

Virtual Simulation Environment:

3D Visualization:
- Vegetation, Fire
- Autonomous mobile Robots
- Stereo 3D
- Tools: OSG, ODE, Demeter

Published at SVR 2007 (Symposium on Virtual and Augmented Reality)
G. Pessin, F. Osório, S. Musse, V. Nonnenmacher, S. Ferreira
http://pessin.googlepages.com/robombeiros
Robombeiros - Fire Fighting VR Simulation

Virtual Simulation Environment:

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

http://pessin.googlepages.com/robombeiros
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6. Conclusions and New Trends
A 3D Fax Machine based on Claytronics

Padmanabhan Pillai, Jason Campbell
Intel Research Pittsburgh
Pittsburgh, PA 15213

Gautam Kedia, Shishir Moudgal, Kaushik Sheth
Carnegie Mellon University
Pittsburgh, PA 15213

Abstract—This paper presents a novel application of modular robotic technology. Many researchers expect manufacturing technology 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.

[Published at IROS2006]
IEEE Intelligent Robot and Systems Conference

http://www.cs.cmu.edu/~claytronics/
Conclusions and New Trends

Virtual Reality Environments:

Geometric + Kinematic + Physical + Behavioural + Cognitive

=  

Realistic VR Environments

New Trends:

VR + Physics
Artificial Intelligence
AR - Augmented Reality
Haptic Interfaces

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<td>More Real</td>
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UNISINOS University - Brazil

Applied Computing Research Post-grad Program - PIPCA
Autonomous Vehicles Research Group - GPVA

Web: Google - veículos autonomos

GPVA Web Page:
http://www.eletrica.unisinos.br/~autonom

Contact - Web Page:
http://inf.unisinos.br/~osorio/

This conference - Web Page:
http://inf.unisinos.br/~osorio/palestras/cerma07.html

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