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

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

Virtual Reality

Introduction VR - Virtual Reality

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

Introduction VR - Virtual Reality

VISUALIZING 3D & VIRTUAL ENVIRONMENTS

Virtual Reality...

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

Augmented Reality

Real World Integrated with Virtual Objects

IRISA / INRIA - France
Virtual Reality

VISUALIZING 3D & VIRTUAL ENVIRONMENTS

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

Movement

How to do it?
Interaction Real x Virtual
"Physics Realism"

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

Cognitive Modeling

Behavioral

Physical

Kinematic

Geometric

[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

[Funge 1999]

[CromosLab]

[Chapiro - Dance]
1. Introduction

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Cognitive  Modeling

Behavioral

Physical

Kinematic

Geometric

[Funke 1999]

[Image of Sony Dream Robot simulated into Webots]

[Image of Sony Dream Robot in the real world]
2. VR and Simulation

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

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2. VR and Simulation

Sources of Inspiration:

3D Virtual Worlds - Hierarchy of Models

Virtual World

Real World

Increasing Reality in VR Applications: Physical and Behavioral Simulation

Realistic VR

Virtual World

Real World

Real World Simulation
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

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

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, ...

ODE - Open Dynamics Engine

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

Webots
Cyberbotics
3. Physics Simulation Tools

* **ODE - Open Dynamics Engine**

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...

REAL TIME SIMULATION
4. Intelligent Behaviour

Intelligent Agents:

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

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 ———> Robotic
Multi-Agents Systems ———> Teams, Squads, Swarms
Knowledge / Reasoning ———> Artificial Intelligence Tools

Presentation Topics

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6. Conclusions and New Trends
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

- 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)

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

Autonomous Robots in VR Environments

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

Milton Roberto Heinen - Applied Computing / Unisinos
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Prof. Dr. Christian Kelber - Electrical Engineering / Unisinos
5. Applications: SEVA 3D

Autonomous Robots in VR Environments

SEVA 3D Simulator

> Vehicle Simulation  x  Vehicle Control

SimRob3D

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

Motor Actions

Kinematics: Estimation of Position and Orientation

3D World

Robot Model

Perception: Sensor Simulation

Sensorial Information

Visualization

Commands

Sensors

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:

- Searching parking space
- Positioning outside
- Stopped
- Enrollment
- Aligning
- Positioning Inside

Automaton states
5. Applications: SEVA 3D

SEVA: NEURAL FSA - Learning the FSA...

- **SENSORS**
  - $S(t) + S(t-1) + ...$
  - Temporal Window

- **CURRENT STATE**
  - NEURAL NETWORK

- **STEERING WHEEL**
- **SPEED**
- **NEXT STATE**

- **VEHICLE**

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

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SEVA3D - Autonomous Vehicle Parking Simulator

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

Applications @ Unisinos

1. Autonomous Robots in VR Environments

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   SEVA 3D - Autonomous Vehicle Parking

   ➤ LEGGEN - Legged (articulated) Robots Simulator

   Robombeiros - Multi-Robots Fire Fighting

Legged Robots Evolution and Walking Control

Sources of Inspiration:

Autonomous Robots in VR Environments

[EPFL]
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

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

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**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, Canadá
- 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*

*Tetrapod Video - "bloopers"*
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 - 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]
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)

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

http://pessin.googlepages.com/robombeiros
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New Trends

A 3D Fax Machine based on Claytronics

Padmanabhan Pitlin, 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. Using manufactured modules that form an intelligent “fax” which can be reshaped via the external application of mechanical forces. This shape can act as a novel input device, using inter-module 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

Claytronics - Nanotech
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

**Autonomy**
Intelligent Virtual Reality Environments

**Simulation**
Virtual Reality Physical and Behavioral Simulation

**More Real**
VR++

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

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