Autonomous Vehicles:

Research, Design and Implementation of Intelligent Autonomous Vehicles

Autonomous Vehicles Research Group - GPVA
http://www.eletrica.unisinos.br/~autonom

Tutorial page: http://inf.unisinos.br/~osorio/palestras/cerma07.html

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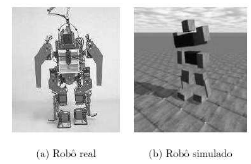
M.Sc. Farlei Heinen - Computer Engineering B.Sc. (Director)

Veículos Autônomos Inteligentes

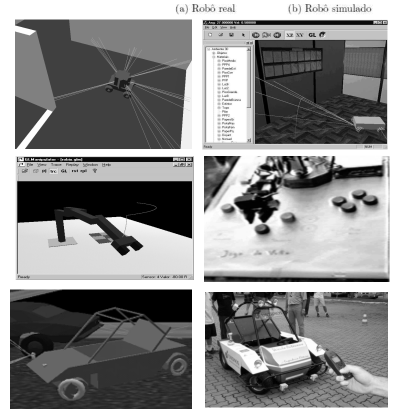
- Introduction
- Robotic: Automatons, Mobile Robots and Autonomous Robots
  - ⇨ Perception, Action, Locomotion e Communication
  - ⇨ Control and Intelligence
- Intelligent Vehicles
  - ⇨ Technologies for Vehicle Automation
  - ⇨ Control pyramid
- Intelligent Control of Autonomous Vehicles
  - ⇨ *Control: Computational Architectures*
  - ⇨ *Simulation of Autonomous Vehicles*
- Computer Vision
- Practical Applications

CONTROL: Computational Architectures

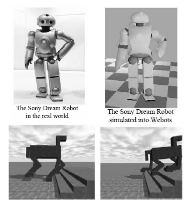
=> From where do I start? *Modeling and Simulation*



- Models:
  - Sensorial Models
  - Actuator Models
  - Kinematics Models
  - Environment Models
  - A.I. Models (Path Planning, Agents, ...)

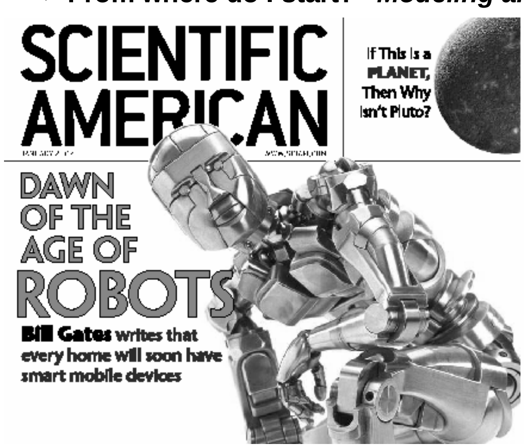


- Simulation:
  - Validate models
  - Test robustness
  - Improve design

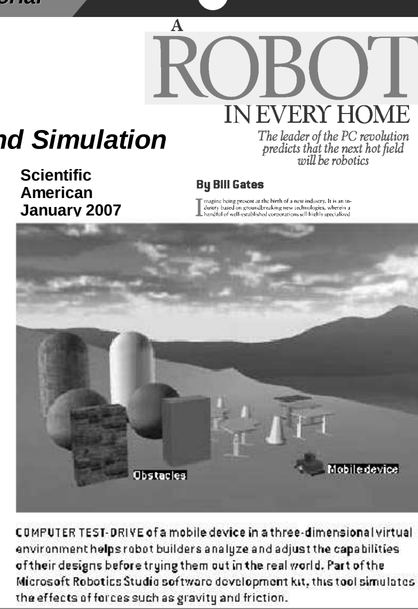


CONTROL: Computational Architectures

=> From where do I start? *Modeling and Simulation*

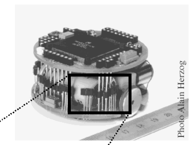
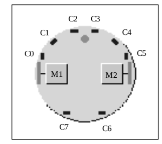
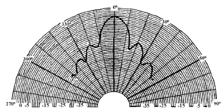


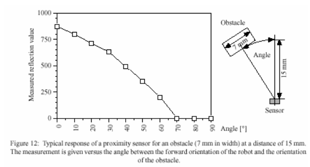
Scientific American
January 2007



CONTROL: Computational Architectures

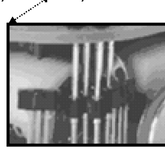
- Sensorial Models
- Kinematics Models



Sensorial Model:

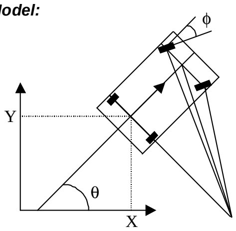
- **Sonar**
- **Infrared**
- **Radar, Compass, Odometer**

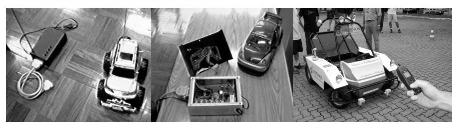


Kinematics Model:

- **Differential**
- **Aeckerman**

Aeckerman



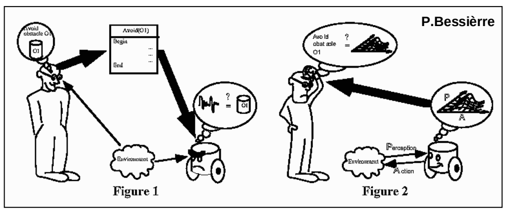


$\theta = V / L * \sin(\Phi)$
$X = V * \cos(\Phi) * \cos(\theta)$
$Y = V * \cos(\Phi) * \cos(\theta)$

CONTROL: Computational Architectures

- Sensorial Models
- Kinematics Models
- Robotic Control:
  - * Reactive
  - * Deliberative
  - * Hierarchical
  - * Hybrid
- Environment Maps
  - * Building Maps
  - * Path Planning
  - * SMPA - *Sense Model Plan Act*
- Problems:
  - * Complex tasks
  - * Avoid Obstacles: Static / Mobile - **Unexpected obstacles**
  - * Robot actual position estimation - **Where am I ?**

CONTROL: Computational Architectures

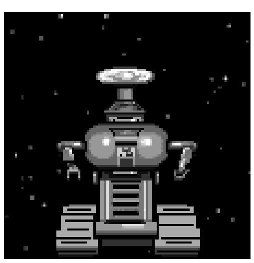


Complexity...

*** Action Planning**
*** Ability to Perceive the Environment**
*** Ability to Decide**
*** Ability to Act**
*** High Level Tasks Planning**
*** Reaction: Sensorial-Motor**
*** Estimate Actual and Future States**
*** Adaptation and Learning**
*** Robustness**
*** Unexpected Situations**

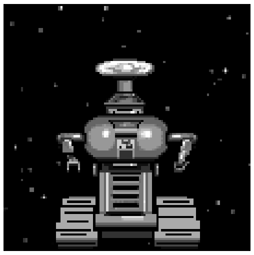
=> From where do I start ???

CONTROL: Computational Architectures

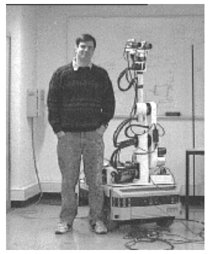


Complexity...

CONTROL: Computational Architectures

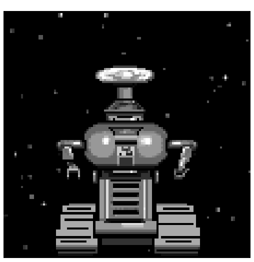


Complexity...

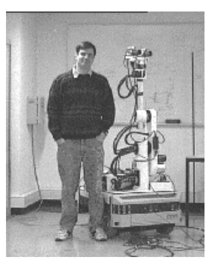


Simplify! How?

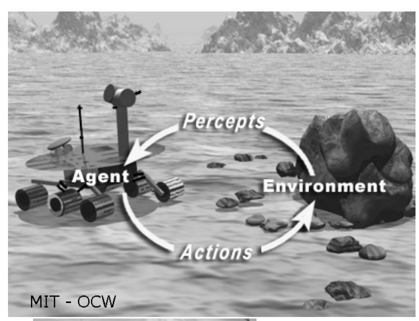
CONTROL: **REACTIVE** Architecture



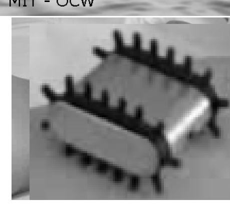
Complexity...



Simplify! How?

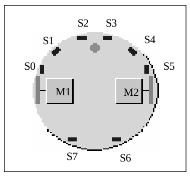


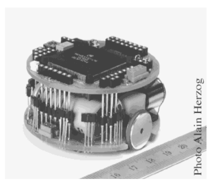
- **Reactive: Sensorial-Motor Integration**
  - **Able to Act**
  - **Able to Perceive the Environment**
    - **Able to React**

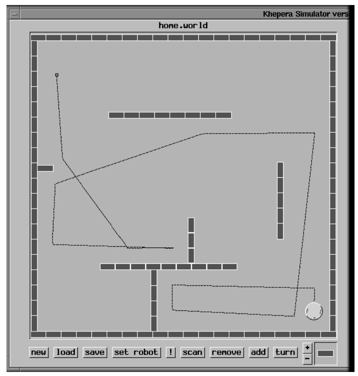


CONTROL: **REACTIVE** Architecture

• Reactive: Sensorial-Motor Integration







Sensorial-Motor: Perceive => Act

Reactive Control

IF S1 < Threshold *and*
S2 < Threshold *and*
S3 < Threshold *and*
S4 < Threshold
THEN Action (Go_Forward)

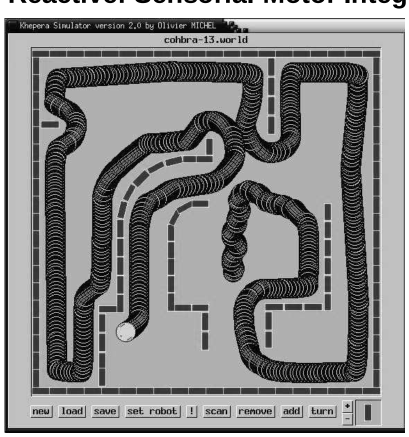
IF S1 < Threshold *and*
S2 < Threshold *and*
S3 > Threshold *and*
S4 > Threshold
THEN Action (Turn_Left)

IF S2 > Threshold *and*
S3 > Threshold *and*
S2 > S3 *and*
S1 > S4
THEN Action (Turn_Right)

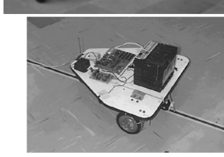
CONTROL: **REACTIVE** Architecture

• Reactive: Sensorial-Motor Integration

Reactive Control



Sensorial-Motor: ***Avoid Obstacles, Wall Following, Wander***



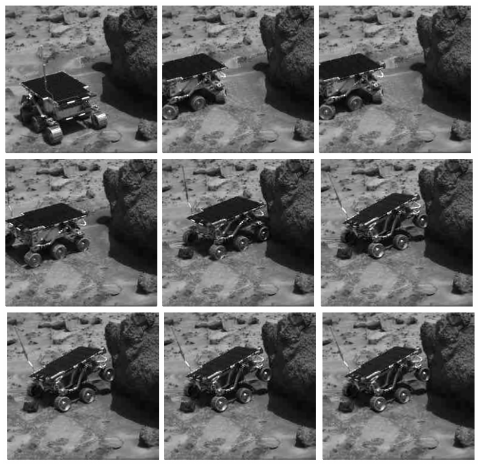
Robotic Lawn Mowers
- Toro iMow
- Husqvarna Auto Mower
- Automower Electrolux →

Electrolux Trilobite
Robotic Vacuum Cleaner ZA1

http://www.onrobo.com/reviews/At_Home/Vacuum_Cleaners/

CONTROL: **REACTIVE** Architecture

- **Reactive: Sensorial-Motor Integration**



Reactive Control

The rover goes a little too far and begins to climb Yogi (NASA)

Sensorial-Motor:

- ***Avoid Obstacles***
- ***Wall Following***
- ***Wander***

Simple behaviors…
Robustness? Complex tasks?

CONTROL: **DELIBERATIVE** Architectures

Deliberative Control

- **Deliberative: Planning + Action**

SIMROB (2D)

- **Map**
- **Configuration Space**
- **Visibility Graph**
- **Optimized Path (Dijkstra)**

Robotic Arm: Pre-defined paths

Deliberative Control

CONTROL: **DELIBERATIVE** Architectures

- **Deliberative: Planning + Action**

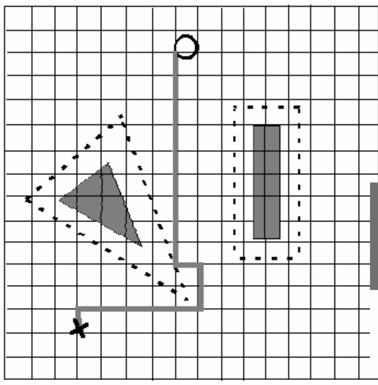
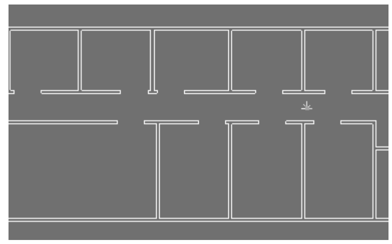
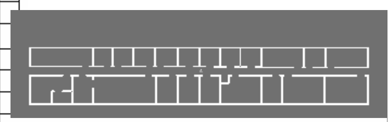


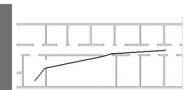
Figura 4.3 Navegação baseada em *Grid*

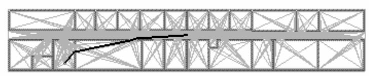
Tarefas Complexas...

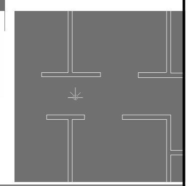
Robustez?
Imprevistos?
Ambiente pouco conhecido?











Geometric Map based Navigation:
Planning: Graph+Dijkstra, A*
Grid based Navigation:
Planning: A*

Hierarchical and Hybrid Control

CONTROL: **HIERARCHICAL and HYBRID Architectures**

Combining: Deliberative + Reactive

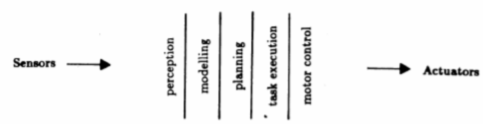


Figure 1. A traditional decomposition of a mobile robot control system into functional modules.

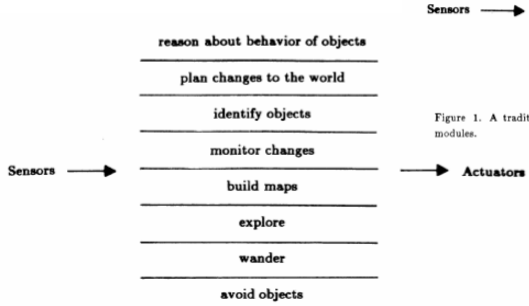


Figure 2. A decomposition of a mobile robot control system based on task achieving behaviors.

Hierarchical Control:

- **Control Layers**
- **Priorities**
- **Information Exchange**

Figures From:
Brooks, R. A.
MIT A.I. Memo 864
Sept. 1985

Brooks - Subsumption Architecture

Hierarchical and Hybrid Control

CONTROL: **HIERARCHICAL and HYBRID Architectures**

Building the Environment Map:

SMPA - SENSE / MODEL / PLAN / ACT

S E N S E

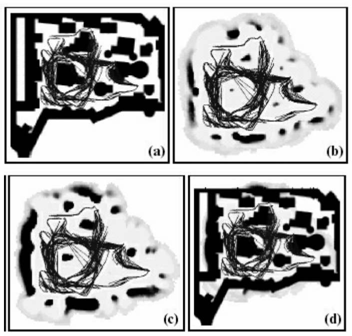


Fig. 9. Integrating multiple maps: (a) CAD map of the museum ($21 \times 20m^2$) modeling only the static obstacles, (b) laser map, (c) sonar map, and (d) the integrated map used for path planning.

MODEL

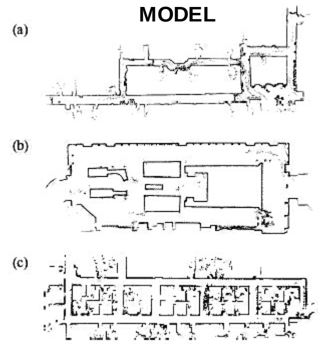


Figure 5: Maps generated in other large-scale environments of sizes (a) 75m, (b) 45m, and (c) 50m. In some of these runs, the cumulative odometric error exceeds 30 meters and 90 degrees.

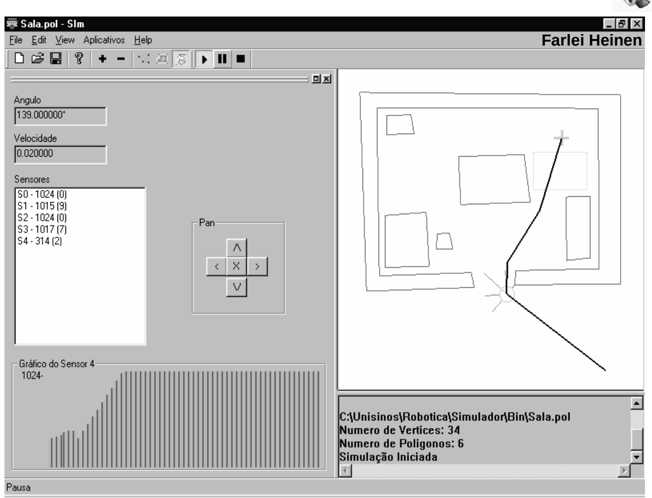
PLAN: AStar Dijkstra

ACT !

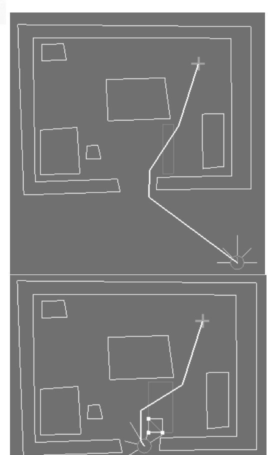
Sebastian Thrun / CMU

Hybrid Control

CONTROL: **Simple HYBRID Architectures**



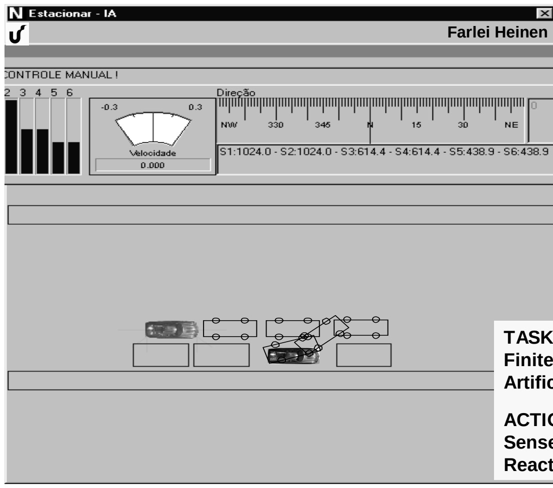
Farlei Heinen

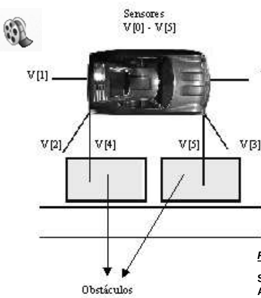


PLAN: Dijkstra
ACT & ReACT

Hybrid Control

CONTROL: Simple HYBRID Architectures





TASK PLANNING & CONTROL:
Finite State Automata (FSA)
Artificial Neural Net (ANN)

ACTION:
Sense, Act
React (change state)

***References*:**

SEVA2D / SEVA3D Autonomous Vehicle Parking

SEVA-A (Automaton) Farlei Heinen

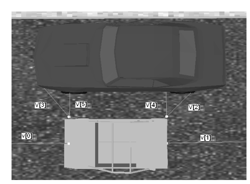
SEVA-N (Neural) Farlei Heinen, Fernando Osório, Luciane Fortes, Milton Heinen

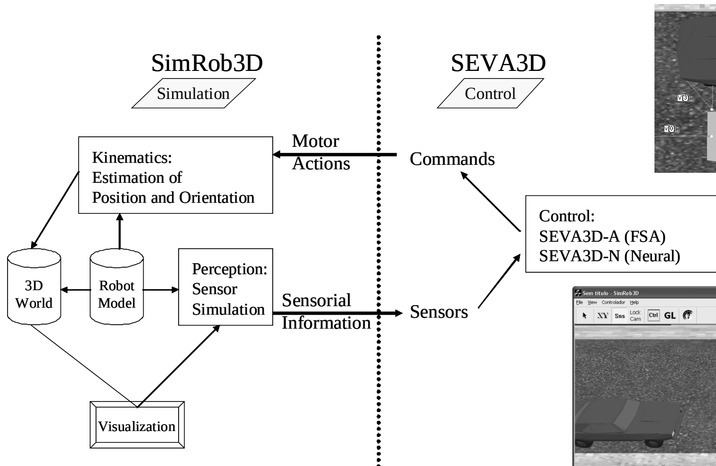
Publications:

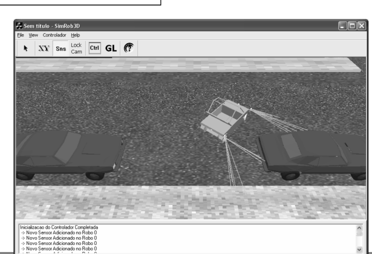
SBRN 2002
WCCI 2006

Hybrid Control

CONTROL: Simple HYBRID Architectures







CONTROL: Computational Architectures

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  - * Deliberative
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  - * Hybrid
- Environment Maps
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  - * SMPA - *Sense Model Plan Act*
- Problems:
  - * Complex tasks
  - * Avoid Obstacles: Static / Mobile - **Unexpected obstacles**
  - * Robot actual position estimation - **Where am I ?**

Intelligent Autonomous Vehicles
Control System
Task Execution

PROBLEMS:

*** Avoid Obstacles**

- **Known Obstacles**
- **Unknown Obstacles (static / no movement)**
- **Unknown Obstacles (dynamic / moving objects)**

*** Positioning**

- **How to determine the exact actual position of the robot ?**
- **How to maintain the control of exact position after displacement ?**
- **Error and Imprecision: Move forward / Rotate**

Intelligent Autonomous Vehicles
Control System
Task Execution

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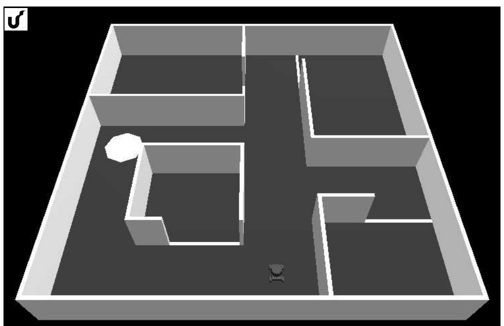

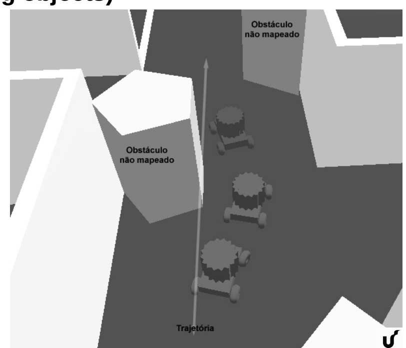

Intelligent Autonomous Vehicles
Control System
Task Execution

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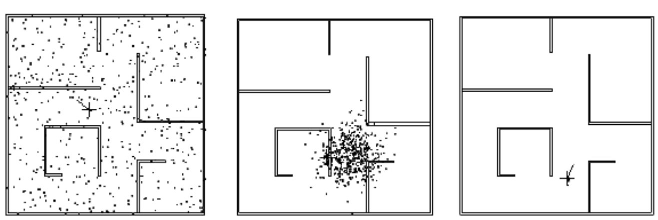
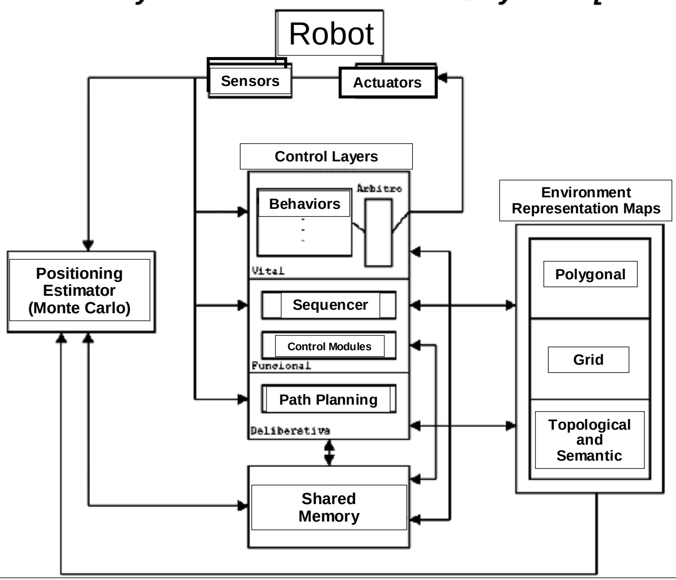


Fig. 2. Seqüência de imagens mostrando a evolução da distribuição das partículas durante a localização do robô móvel utilizando o algoritmo Monte Carlo.

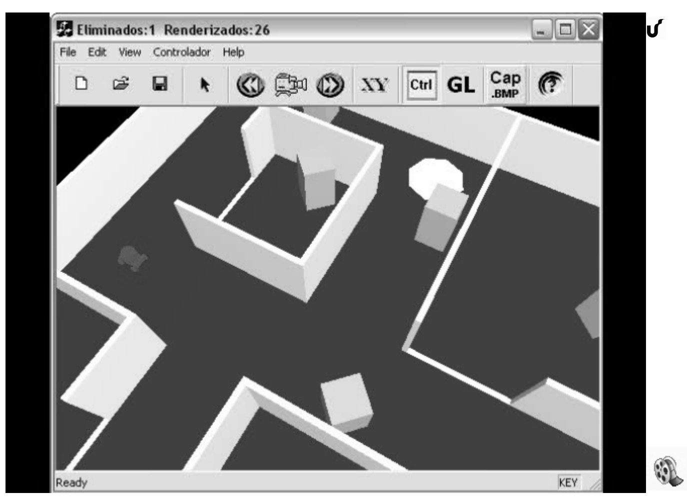
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]



COHBRA – Controle Híbrido de Robôs Autônomos
HyCAR - Hybrid Control for Autonomous Robots

Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

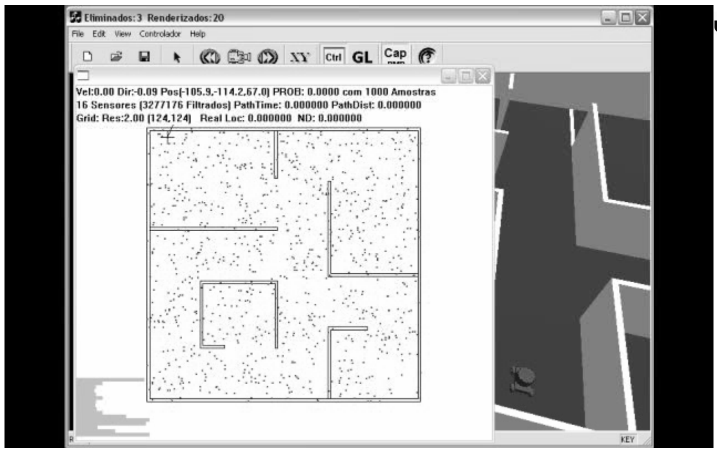
Simulation using SimRob3D



Intelligent Autonomous Vehicles

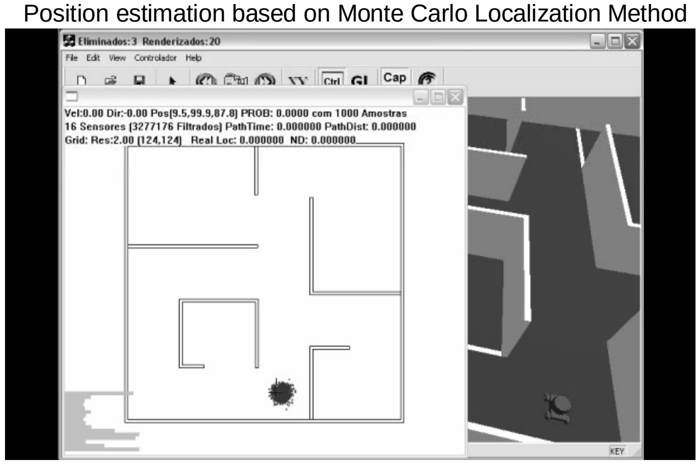
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Simulation using a static environment
Position estimation based on Monte Carlo Localization Method



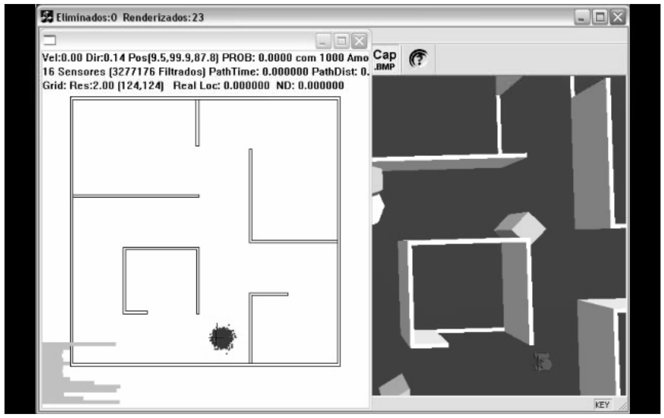
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Simulation using a static environment
Position estimation based on Monte Carlo Localization Method



Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

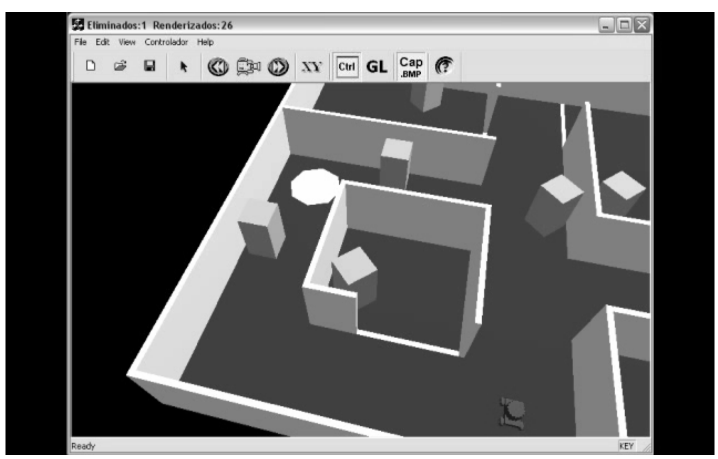
Simulation using a static environment
Environment was changed related to the original map
Internal robot representation is different from actual world configuration



CERMA 2007
IEEE computer society
CERMA 2007 / Tutorial
UNISINOS

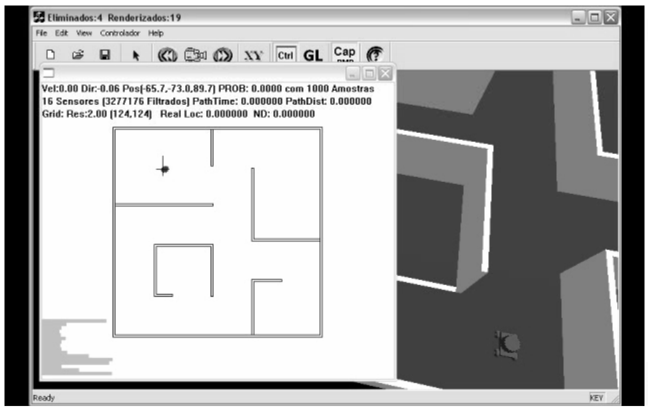
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Simulation using a dynamic environment (mobile obstacles)



Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Position estimation based on Monte Carlo Method:
Robot was moved, starting in a new and unknown position



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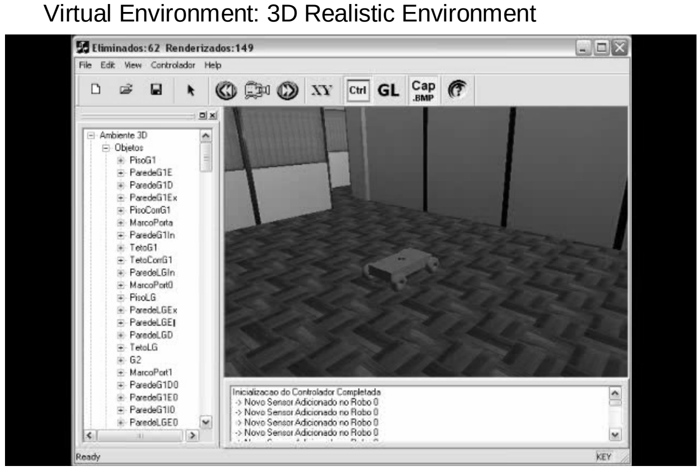
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Virtual Environment: 3D Realistic Environment

SimRob3D Simulation Tool



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Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

Virtual Environment: 3D Realistic Environment

SimRob3D Simulation Tool

Robust Hybrid Control

Intelligent Autonomous Vehicles

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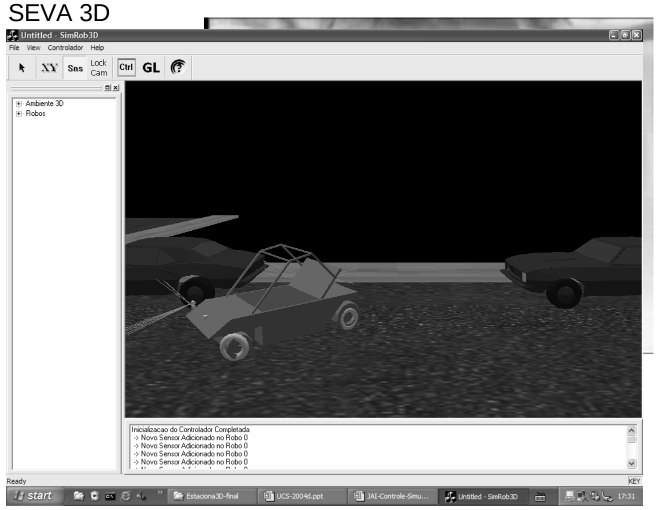
Robust Hybrid Control – COHBRA / HyCAR [SimRob3D]

SEVA 3D



SimRob3D Simulation Tool

Robust Hybrid Control

Intelligent Autonomous Vehicles

Intelligent Autonomous Robots and Vehicles
<< Intelligence >>

* Task and Actions Planning
* Ability to Perceive the Environment
* Ability to Decide
* Ability to Act
* High Level Tasks Planning
* Reaction: Sensorial-Motor Integration
* Estimate Actual and Future States:
  Environment + Behavior = Interaction
* Adaptation and Learning
* Robustness: Unexpected Situations

Next steps...

Intelligent Autonomous Robots and Vehicles
<< Intelligence >>

* Task and Actions Planning
* Ability to Perceive the Environment
* Ability to Decide
* Ability to Act
* High Level Tasks Planning
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* Estimate Actual and Future States:
  Environment + Behavior = Interaction
* Adaptation and Learning
* Robustness: Unexpected Situations

Next steps...

DARPA Challenge - Desert (2004, 2005)

DARPA Challenge - Urban (2007)

Intelligent Autonomous Robots and Vehicles
<< Intelligence >>

* Task and Actions Planning
* Ability to Perceive the Environment
* Ability to Decide
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* Reaction: Sensorial-Motor Integration
* Estimate Actual and Future States:
  Environment + Behavior = Interaction
* Adaptation and Learning
* Robustness: Unexpected Situations

Next steps...

Computational Vision

Intelligent Autonomous Robots and Vehicles
<< Intelligence >>

Computational Vision

- Path following:
  - Follow Me, Lane Follow
- Avoid danger situations: going out of the track
  - Lane Detection
- Obstacle detection: pedestrians, cars, etc
- Traffic signs detection and recognition
- Visual Navigation (Based on Images)

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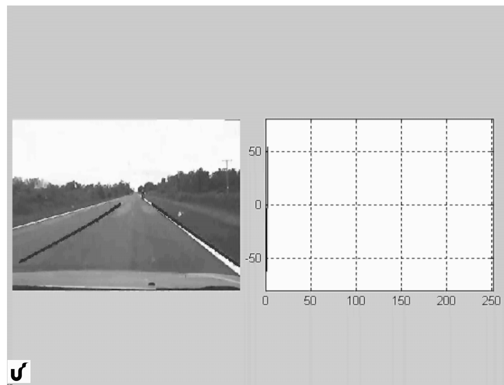
Intelligent Autonomous Robots and Vehicles
<< Intelligence >>

Computational Vision

Follow Me

Lane Follow
Lane Departure Detection



Computational Vision

Intelligent Autonomous Vehicles

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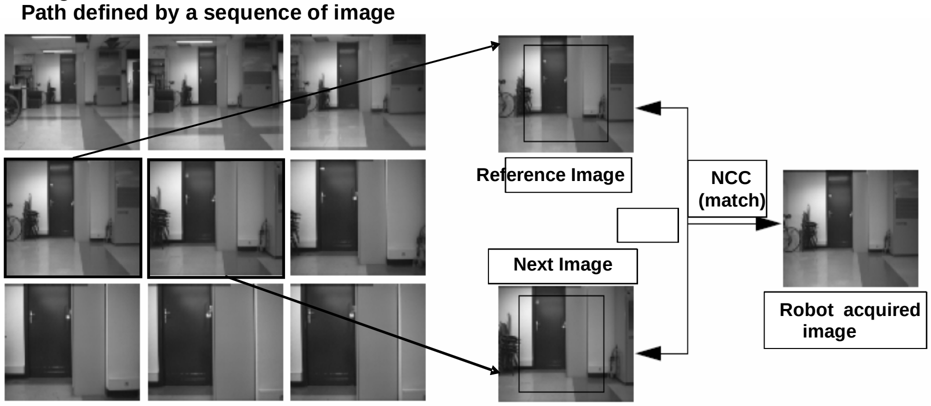
Visual Navigation

Image Database:
Path defined by a sequence of image



Navigation based on Monochromatic Images [Jones et al. 1997]

Algorithm: NCC – Normalized Cross-Correlation

Visual Navigation

Intelligent Autonomous Vehicles

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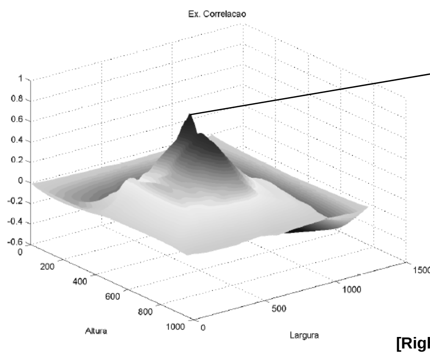
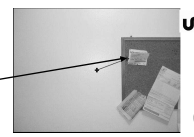
Visual Navigation

Matlab Code

```
>> img1 = imread('ir\b02ir08.jpg');
>> img2 = imread('icr\b02icr08.jpg');
>> ncc = normxcorr2( img2(:,:,1), img1(:,:,1) );
>> figure,surf(ncc),shading interp,axis ij,view(3);
>> title('Ex. Correlacao'),ylabel('Altura'),xlabel('Largura');
```



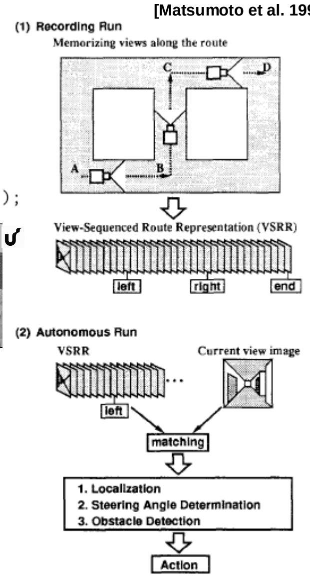


IR:
Reference Image

ICR:
Image Captured by the robot

[Righes 2004, 2005]

[Matsumoto et al. 1996]



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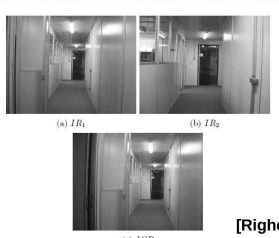
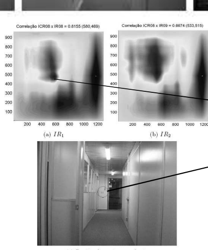
Visual Navigation



(a) IR_1 (b) IR_2

(c) ICR

[Righes 04]



(c) Região de maior correlação

Visual Navigation

Mobile Robot Localization and Mapping with Uncertainty using Scale-Invariant Visual Landmarks

Stephen Se,
David Lowe,
Jim Little
(UBC, CA)

Algorithm:
SIFT

Reference
Int. Journal of Robotics Research
Vol. 21, No. 8, August 2002,
pp. 735-758,

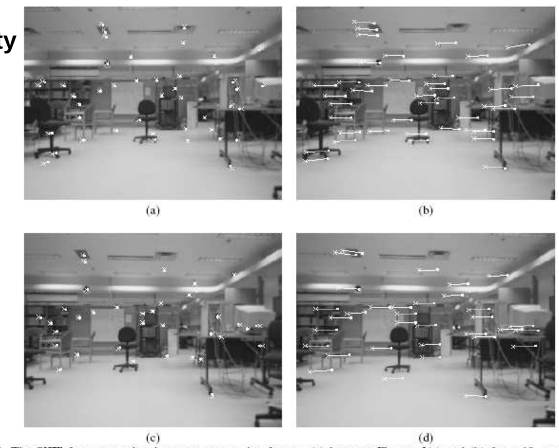
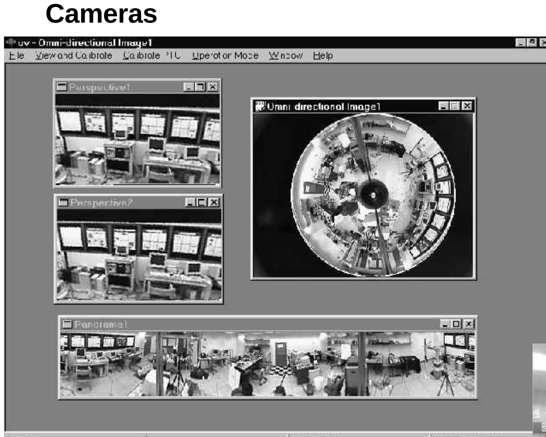
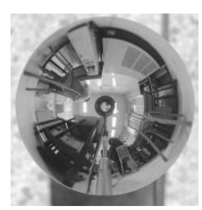


Fig. 3. The SIFT feature matches between consecutive frames: (a) between Figures 2(a) and (b) for a 10 cm forward movement; (b) between Figures 2(b) and (c) for a 5° clockwise rotation; (c) between Figures 2(c) and (d) for a 10 cm forward movement; (d) between Figures 2(d) and (e) for a 5° clockwise rotation.

Visual Navigation

Omnidirectional Cameras





Aerial Visual Navigation

Vision System for Unmanned Aerial Vehicles

Correlation:
Satellite image
and Helicopter

Results...
Not good at all!

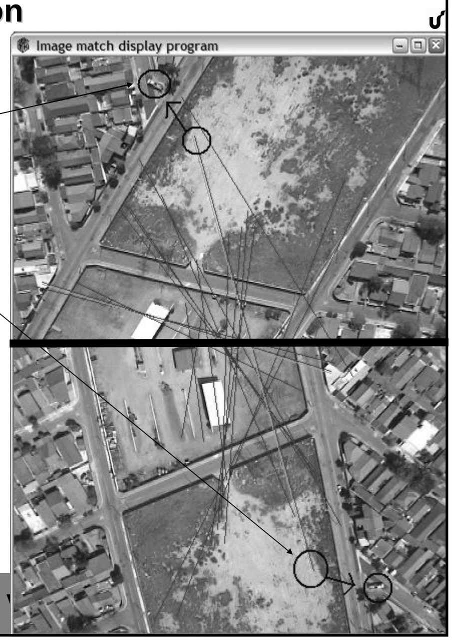
Aerial Visual Navigation

Vision System for Unmanned Aerial Vehicles

Referential

Correlation in the Crossing Point
Using helicopter only images

Very
Good
Match!



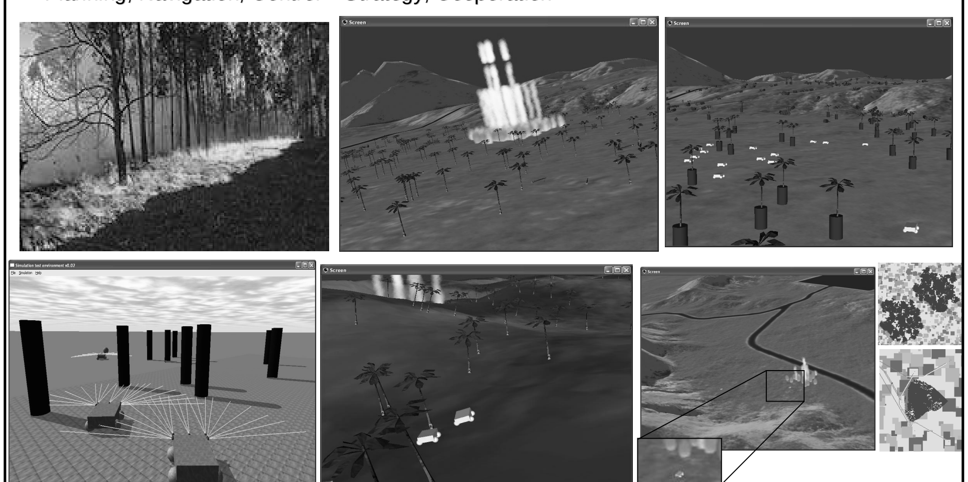
Vehicle Visual System

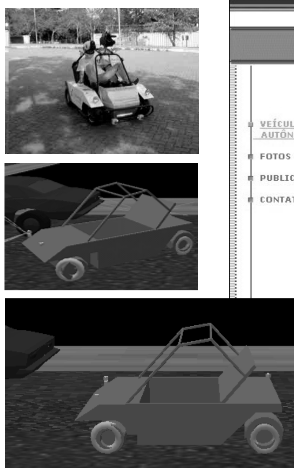
Vision system used to identify traffic signs

Color based sign segmentation
Artificial Neural Network Recognition

Multiple Vehicles: Fire fighting squad

Planning, Navigation, Control + Strategy, Cooperation





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Veículos Autônomos

VEÍCULOS AUTÔNOMOS

- VEÍCULOS AUTÔNOMOS
- FOTOS & VÍDEOS
- PUBLICAÇÕES
- CONTATOS

A Universidade do Vale do Rio dos Sinos - UNISINOS possui um grupo de pesquisa de nome: *Veículos Autônomos*.

Este grupo multidisciplinar, envolvendo pesquisadores dos Cursos de Engenharia Elétrica, Engenharia da Computação, Engenharia Mecânica, Engenharia Civil e do Programa Interdisciplinar de Pós-Graduação em Computação Aplicada (PIPCA), desenvolve e implementa tecnologias para automação veicular em *veículos inteligentes*, que podem, por exemplo, mover-se de forma completamente autônoma.

Para alcançar este objetivo maior, diferentes sub-sistemas e tecnologias são desenvolvidos, muitos destes através de parcerias com a indústria.

Dentre os objetivos dos diferentes projetos desenvolvidos pelo grupo destacam-se:

- Desenvolvimento da tecnologia *Drive-By-Wire*.
- Desenvolvimento de *Sistemas de Apoio ao Motorista*.
- Desenvolvimento de *Sistemas de Supervisão e Comando Remotos*.
- Aplicações de *Inteligência Artificial* em robótica móvel.
- Aumento de segurança nas estradas.
- Exploração de locais de difícil acesso.
- Inspeções em ambientes de risco à saúde humana.
- Automatização de sistemas de transporte.
- Automação rural.

Os projetos aqui apresentados visam analisar os diversos tipos de sensores, atuadores, sistemas de controle, sistemas de redes e eletrônica embarcada a serem implementados em Veículos Autônomos.

http://www.eletrica.unisinos.br/~autonom

Google: Veículos Autônomos

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Intelligent Autonomous Vehicles