Robotics Workshop

Challenge of large working volumes in the industry

21 March 2013, 13:30 – 15:30 – Lyon – Palais des Congrès

Navigation and localization in large working volumes

Professor Philippe Martinet

IRCCYN Laboratory

Ecole Centrale de Nantes

Philippe.Martinet@irccyn.ec-nantes.fr

http://www.irccyn.ec-nantes.fr/~martinet/

LVMC[1] Large Volume Metrology Conference & Exhibition
Mercure Manchester Picadilly, 1-2 october, 2013

[1] LVMC started in 2005 (Manchester'11,Chester'09(10/12), Liverpool'07(08))

Outline

Introduction

- Applications
- Environment modeling
- Some potential solution

Localization

- Sensor technology
- Global Localization
- Local localization

Navigation

- Modeling
- Control
- Illustrations

Conclusion

- Current status
- Future

Applications

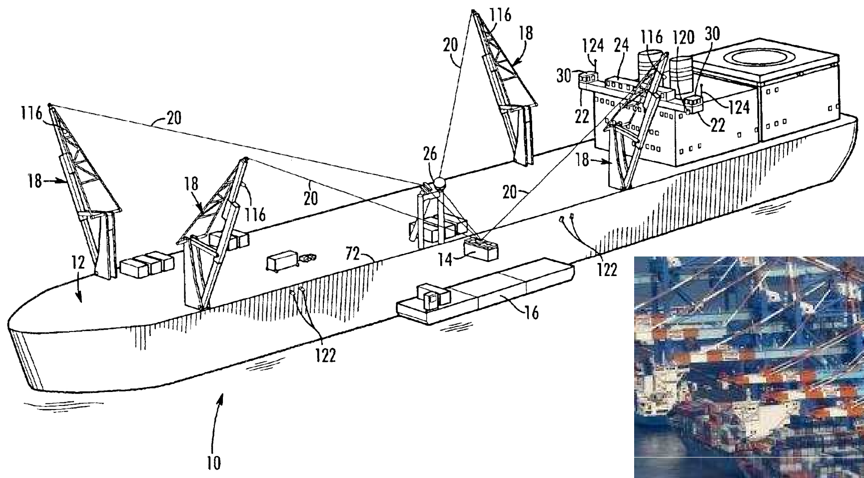


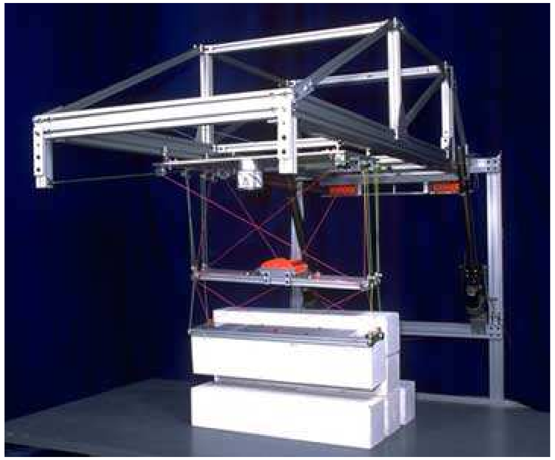
Aerospace
Architecture & Construction
Automotive
Bridge
Defense
Education
Forensics
Foundry
Heavy Machinery
Heritage
…

Accident Reconstruction
Alignment
As-Built Documentation
Asset and Facility Management
Building Information Modeling
CAD-Based Inspection
Crime Scene Analysis
Dimensional Analysis
First Article Inspection
Incoming Inspection
In-Process Inspection
Large Part Inspection
Machine Calibration
Non-Contact Inspection

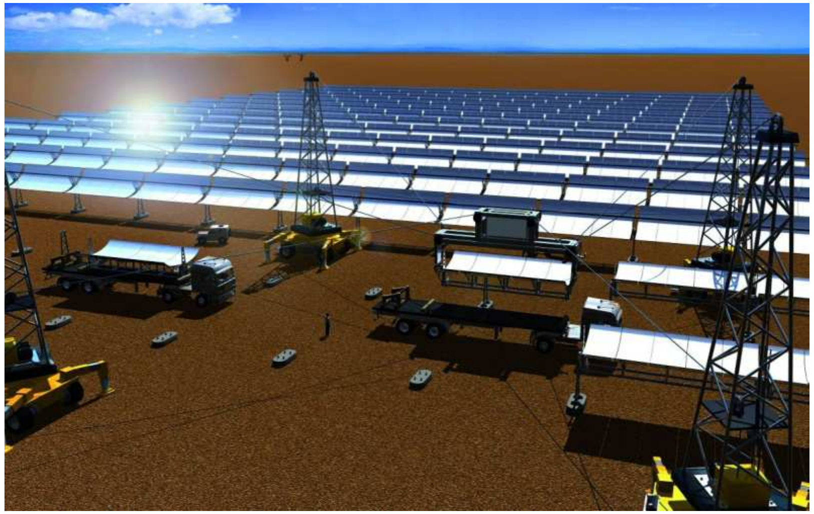
Reverse Engineering
Robot Calibration
Tool Building & Setup
Virtual Simulation
Hydro Power
Law Enforcement
Machine Shop
Medical Systems
Petrochemical
Power Generation
Pulp & Paper
Shipbuilding
Tunnel & Mining
Wind Power

Applications : container handling





Applications : constructions assembly and monitoring



IPAnema : Solar thermal plant construction

Millau viaduct

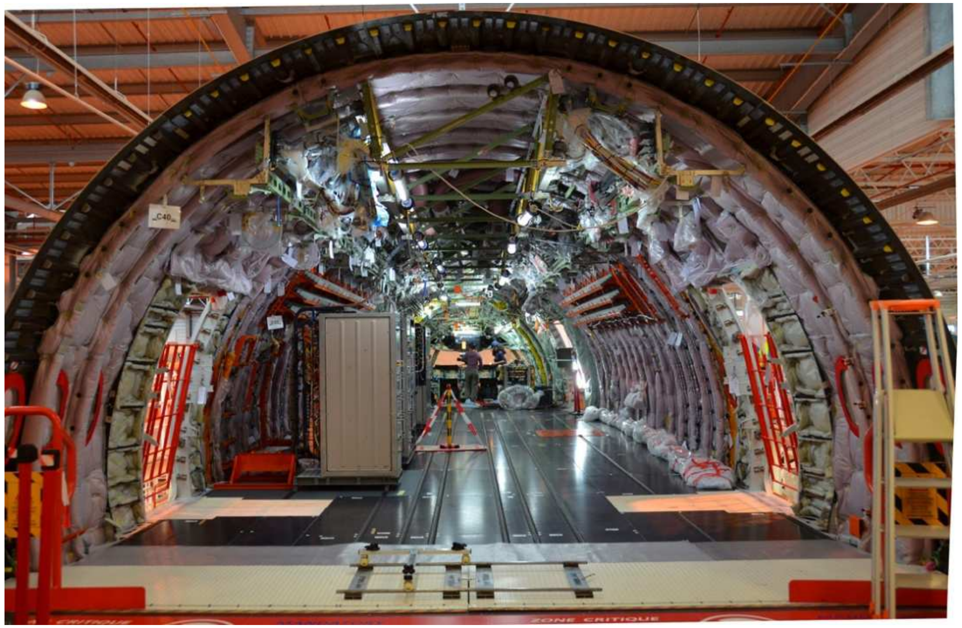
Length: 2460m, heigh : 343 m, Total Weight: 290000 tonne

5mm checking during construction using GPS

Several hundred of sensors (microvibrations sensors, pressure, sensors cameras, GPS, …) for on line monitoring

Applications : deburring, painting, sanding, inspection …

Applications : wiring, wiring checking, drilling, riveting, assembling…



Introduction : Environment modeling

Global 3D Model based approach
- 3D CAD model
- 3D absolute localization

Local 3D model based approach
- 3D CAD model
- 3D local localization

CAD model is consider as a reference

To fit reality, adaptation of some parameters is required

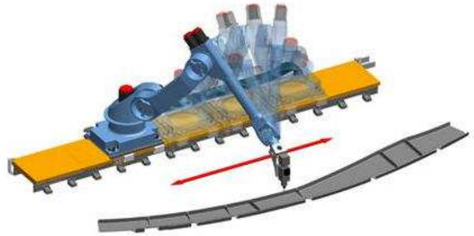
Unknown 3D model approach
- 3D map building (SLAM)
- 3D local localization

3D reconstructed model is consider as a reference

Unknown sensor based approach
- Sensory memory supervised building
- Sensor based localization

Topological representation of the environment is used as a reference
Learning step can be human supervised

Introduction : some potential solution

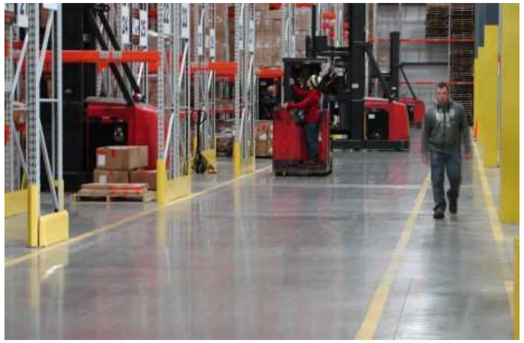


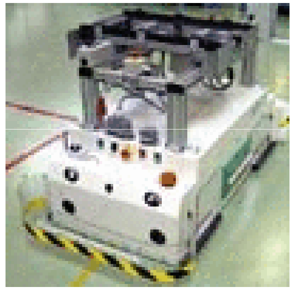
Using a specific infrastructure

Introduction : some potential solution

Non exhaustive

Using a more less light infrastructure





Guidance by
- *Wire (require wire in the ground)*
- *Laser (require reflectors)*
- *Wire/Laser*
- *Vision*

Introduction : some potential solution

Non exhaustive

Using an unknown infrastructure

- **Learning the environment supervised by human (SLAM)**
- **Autonomous learning**

- *Laser*
- *Radar*
- *Vision*
-…

Outline

Introduction
- *Applications*
- *Environment modeling*
- *Some potential solution*

Localization
- *Sensor technology*
- *Global Localization*
- *Local localization*

Navigation
- *Modeling*
- *Control*
- *Illustrations*

Conclusion
- *Current status*
- *Future*

Sensor technology : Laser tracker (Faro, Nikon, Leica)

Non exhaustive

FARO Laser Tracker Vantage
- **Spherical workspace 160 m**
- **Accuracy from 0,015 mm (at 2m)**

FARO Laser Tracker ION
- **Spherical workspace 110 m**
- **Accuracy from 0,015 mm (at 2m)**

Nikon Laser Radar MV330
- **Spherical workspace 60m**
- **Accuracy 0,024mm (at 2m)**

Nikon Laser Radar MV350
- **Spherical workspace 100m**
- **Accuracy 0,024mm (at 2m)**

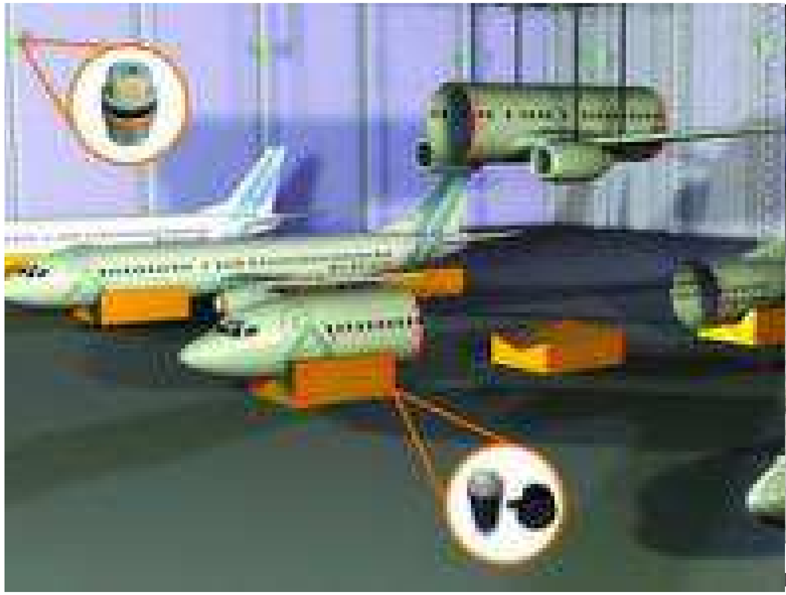
LEICA Laser Tracker AT401
- **Spherical workspace 160m**
- **Accuracy 0,010mm**

LEICA Laser Tracker AT901
- **Workspace 160m**
- **Accuracy from 0,0075mm**

Sensor technology: iGPS (Nikon)

Volume : 10x10m up to 40x40m

Accuracy < 200µm over monument volume



iGPS system is comparable to a GPS. GPS satellites are replaced by infrared iGPS laser transmitters that activate a measurement field as large as an entire room or facility.

iGPS features accuracies that are roughly a hundred thousand times higher than consumer GPS systems.

AGVs (tools, …) can be equipped with iGPS receivers that are tracked by the transmitters.

To obtain accurate positioning, receivers need line of sight from minimum 2 transmitter fields. Adding more transmitters enlarges the measurement area, improves robustness by guaranteeing line of sight, and further increases measurement accuracy.

Sensor technology : C-track dual camera sensor (Creaform)

Non exhaustive

C-Track	Accuracy	Vol
380	0.057 mm	3.8 m^3
780	0.065 mm	7.8 m^3
1480	0.130 mm	14,8 m^3

C-Track dual-camera sensor

The C-Track dual-camera sensor is a complete portable 3D measurement solution. C-Track dual-camera uses reflectors.

C-Track can be used to measure positions and orientations in space simultaneously and continuously, and with great precision.

This makes it possible to control displacements, drive assembly processes or measure deformations.

Global Localization: external cameras

Network of monocular cameras

- One camera observes one particular volume
- Observed volume have common part
- Calibration of the camera network is required
- Localization in the camera network frame can de done

In case of object tracking :

The object model must be known or at least we must find a way to solve the scale factor ambiguity

Network of stereo cameras

- One stereo pair observes one particular volume
- Observed volume have common part
- Calibration of the network is required
- Localization in the camera network frame can de done

The object model can be unknown.

Remarks: In case of moving objects tracking and localization, Time stamping of the image network data can be required

Local localization: embedded camera(s)

One (or more) embedded camera(s)

- One (or more) camera in the system to be localized
- One complete CAD model of the environment is available
- A graph of views can be generated
- The local localization consist to find the closest view in the graph and to compute the relative pose from it (we suppress here the global localization)

One (or more) embedded camera(s)

- One (or more) camera in the system to be localized
- One complete sensory memory of the environment is available
- A topological graph of views can be generated with the memory
- The local localization consist to find the closest view in the graph and to compute the relative pose from it (we suppress here the global localization)

Remarks: The graph can be generated automatically by using regular sampling, or can be designed with regard to the tasks to be done. (i.e : go to the door and open the door)

Outline

Introduction

- *Applications*
- *Environment modeling*
- *Some potential solution*

Localization

- *Sensor technology*
- *Global Localization*
- *Local localization*

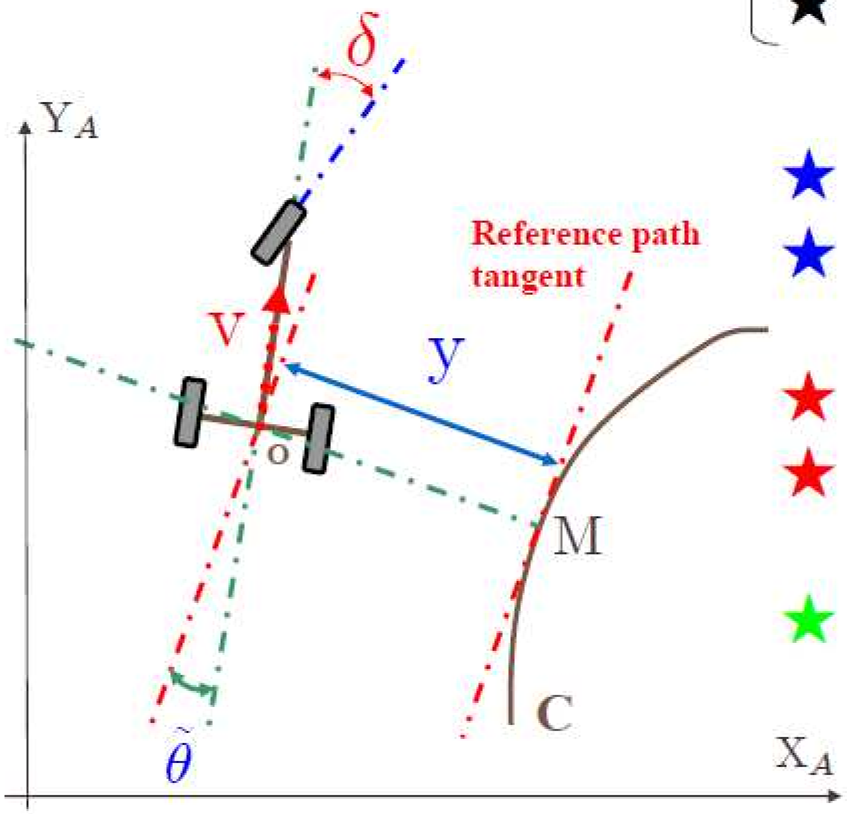
Navigation

- *Modeling*
- *Control*
- *Illustrations*

Conclusion

- *Current status*
- *Future*

Modeling: An example for the car like mobile robot



M { ★ s : curvilinear coordinate
★ $c(s)$: curvature

★ $\tilde{\theta}$: angular deviation
★ y : lateral deviation

★ δ : wheel angle
★ v : vehicle linear velocity

★ l : wheel base length

Control: An example for the car like mobile robot

The vector $(s_i, y_i, \tilde{\theta}_i)$ describes the state of the i^{th} vehicle

Modelling is derived under non-slipping assumptions (tricyle model)
[Samson95, Daviet95, Thuilot04]

→ relies on a kinematic model
→ designed with respect to the reference path

$$\begin{cases} \dot{s}_i = v_i \frac{\cos\tilde{\theta}_i}{1-y_i c(s_i)} \\ \dot{y}_i = v_i \sin\tilde{\theta}_i \\ \dot{\tilde{\theta}}_i = v_i \left(\frac{\tan\delta_i}{l} - \frac{c(s_i)\ \cos\tilde{\theta}_i}{1-y_i\ c(s_i)}\right) \end{cases}$$

Syst Ia

Control objectives

y_{i+1} and $\tilde{\theta}_{i+1}$ to 0

δ_{i+1}

Control: *An example for the car like mobile robot*

[Thuilot04]

Chained state vector $A = (a_{1i}, a_{2i}, a_{3i})^T = \Theta(s_i, y_i, \tilde{\theta}_i) \begin{cases} a_{1i} = s_i \\ a_{2i} = y_{1i} \\ a_{3i} = \tan\tilde{\theta}_i\,(1 - y_i\, c(s_i)) \end{cases}$

Chained Control vector $M = (m_{1i}, m_{2i})^T = \Upsilon(v_i, \delta_i)$

Chained System [Samson95]
Exact linearization

$(*)' = \frac{d}{ds}(*)$

Chained model driven by *s*

Syst Ia $\begin{cases} \dot{a}_{1i} = m_{1i} \\ \dot{a}_{2i} = a_{3i} m_{1i} \\ \dot{a}_{3i} = m_{2i} \end{cases}$ → **Syst IIa** $\begin{cases} a'_{2i} = a_{3i} \\ a'_{3i} = m_{3i} \end{cases}$

→ linear system structure
→ full lateral / longitudinal decoupling

PD control law

$m_{3i} = -k_d\, a_{3i} - k_p\, a_{2i}$ (k_d, k_p) tuning specifies a settling distance

$a''_{2i} + k_d\, a'_{2i} + k_p\, a_{2i} = 0$ → $(a_{3i}, a_{2i}) \to (0,0)$ → $(y_i, \tilde{\theta}_i) \to (0,0)$

Vehicle trajectories are velocity independent

Illustrations: Autonomous Taxi Robot using 3D visual memory

Visual memory

Reference Trajectory

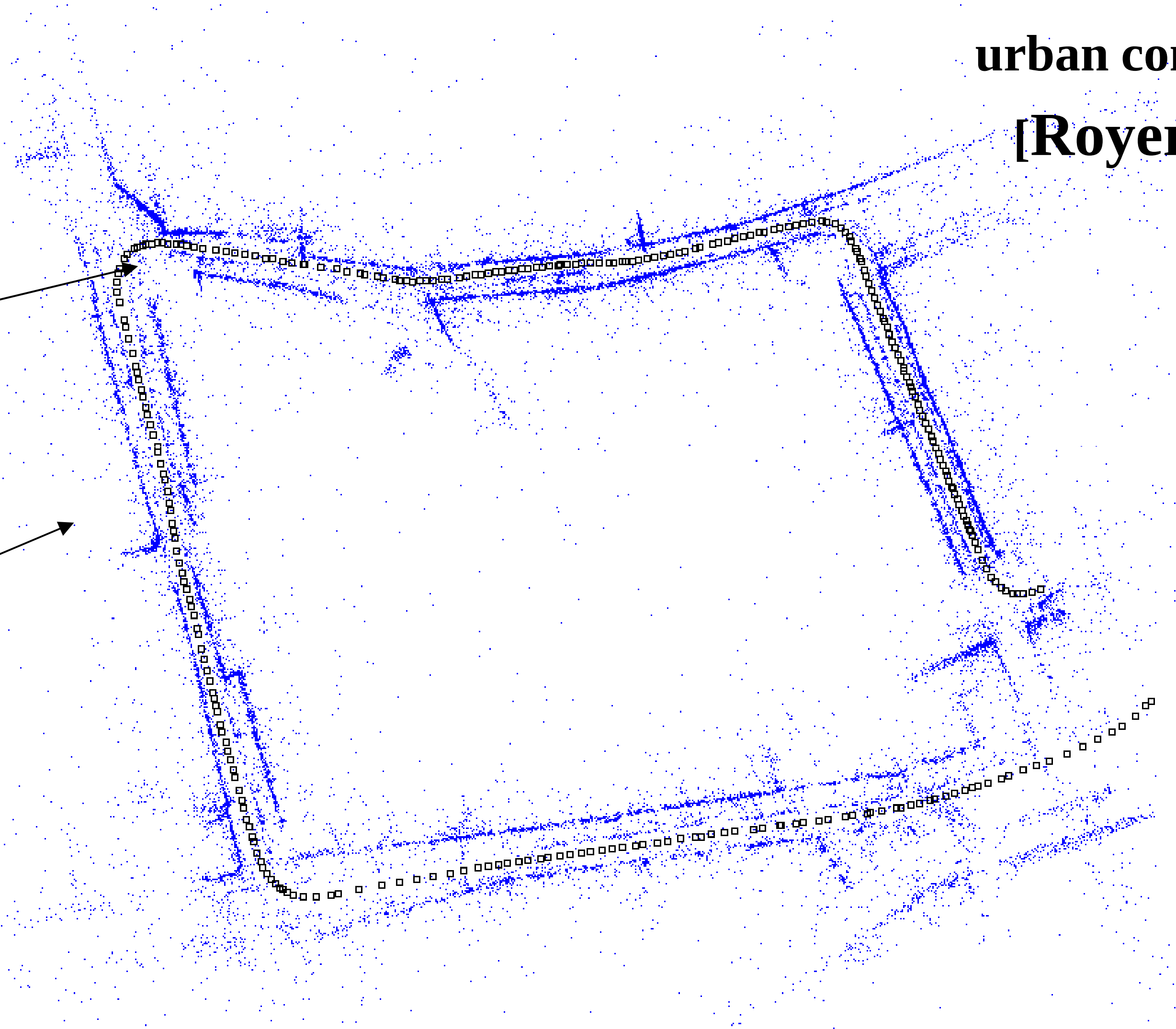
and

Image features (3D points)

Experimental data
Compiegne city center
(BODEGA/MOBIVIP)

urban context

[Royer04]



Illustrations: Autonomous Taxi Robot using 3D visual memory

CITYVIP: Clermont-Fd 2010

Clermont-Fd 2006

Navigation using vision only

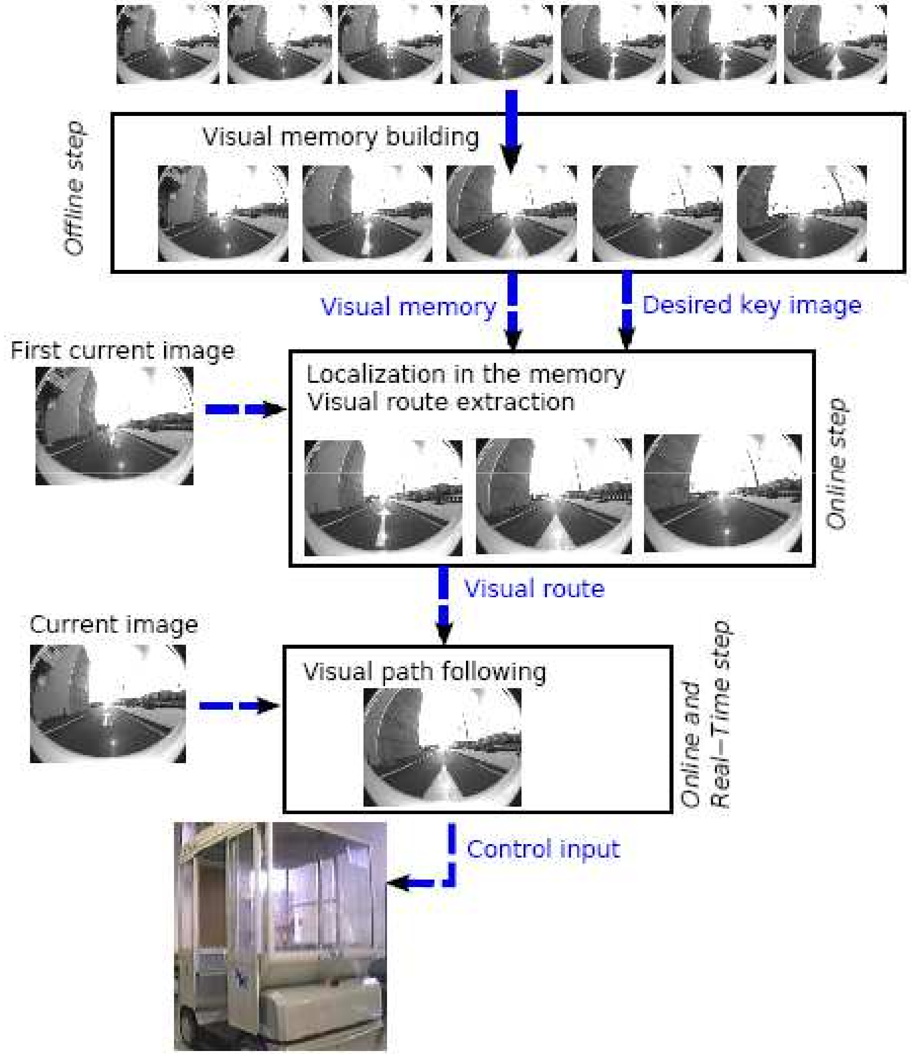
Clermont-Ferrand : LASMEA-GRAVIR

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

ANR

Illustrations: Autonomous Taxi Robot using sensory memory

General framework :



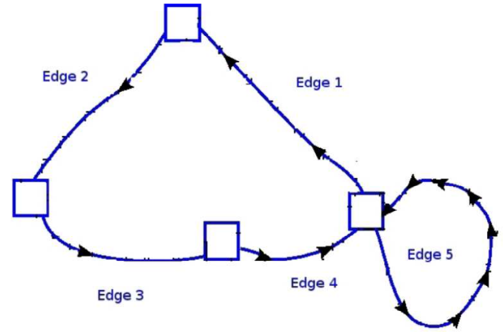
Vision based memory navigation strategy :

3 steps :

1. *Visual memory building*
2. *Localization into the visual memory*
3. *Navigation into the visual memory*

Illustrations: Autonomous Taxi Robot using sensory memory

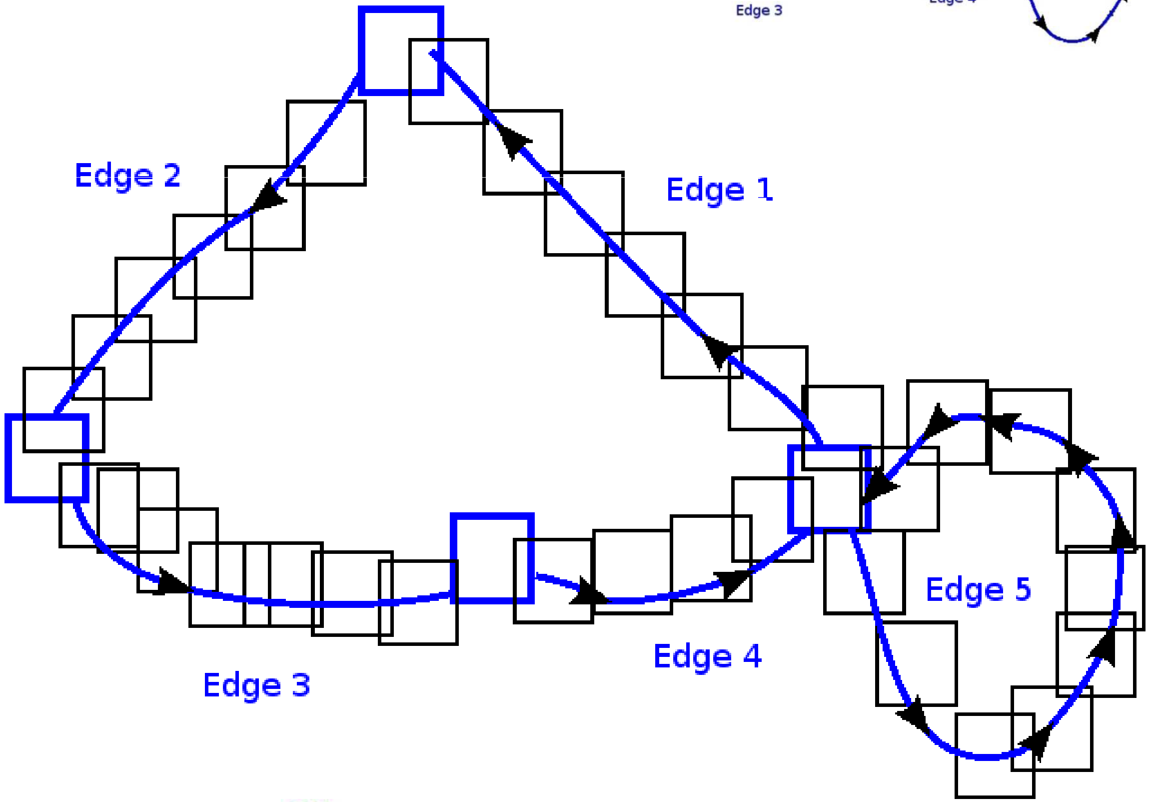
Graph based representation



Vision based memory navigation strategy :

Visual memory building

a-Topological description
b-Learning the environment
c-Extraction of interesting features

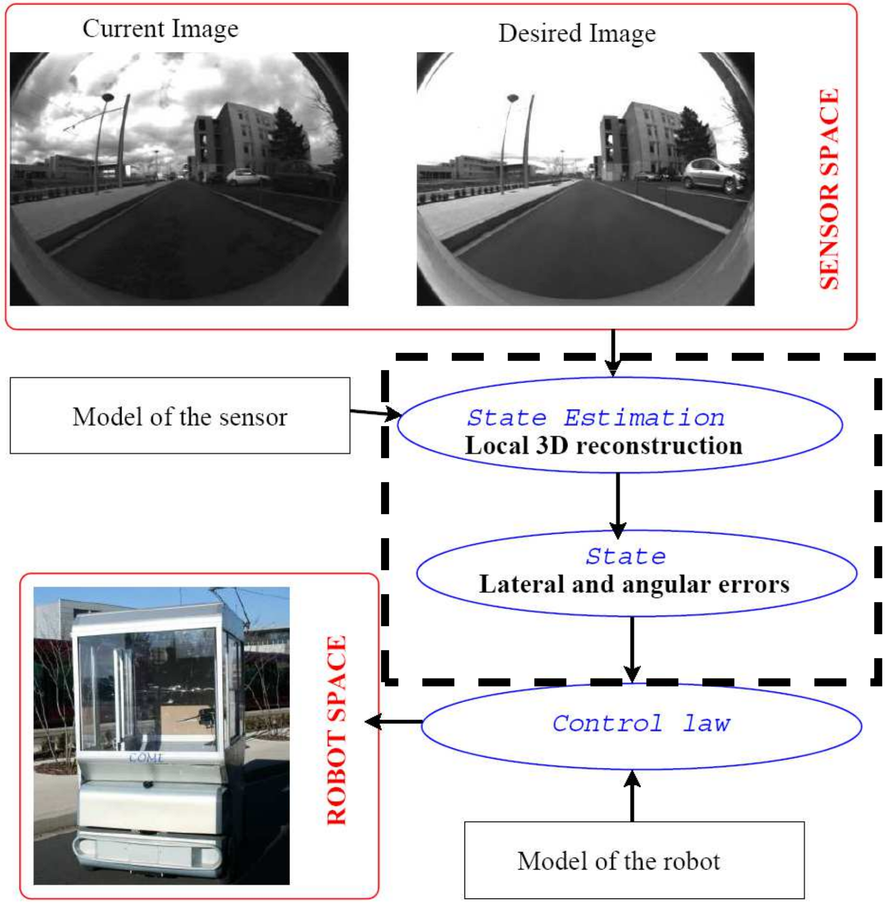


Can be
- **Harris points**
- **Sift features**
- **…**

Illustrations: Autonomous Taxi Robot using sensory memory

AGV using visual memory

Localization



Vision based memory navigation strategy :

Localization into the visual memory

a- Global localization *[ICRA08]*
b- Selection of key images
c- Relative pose computation

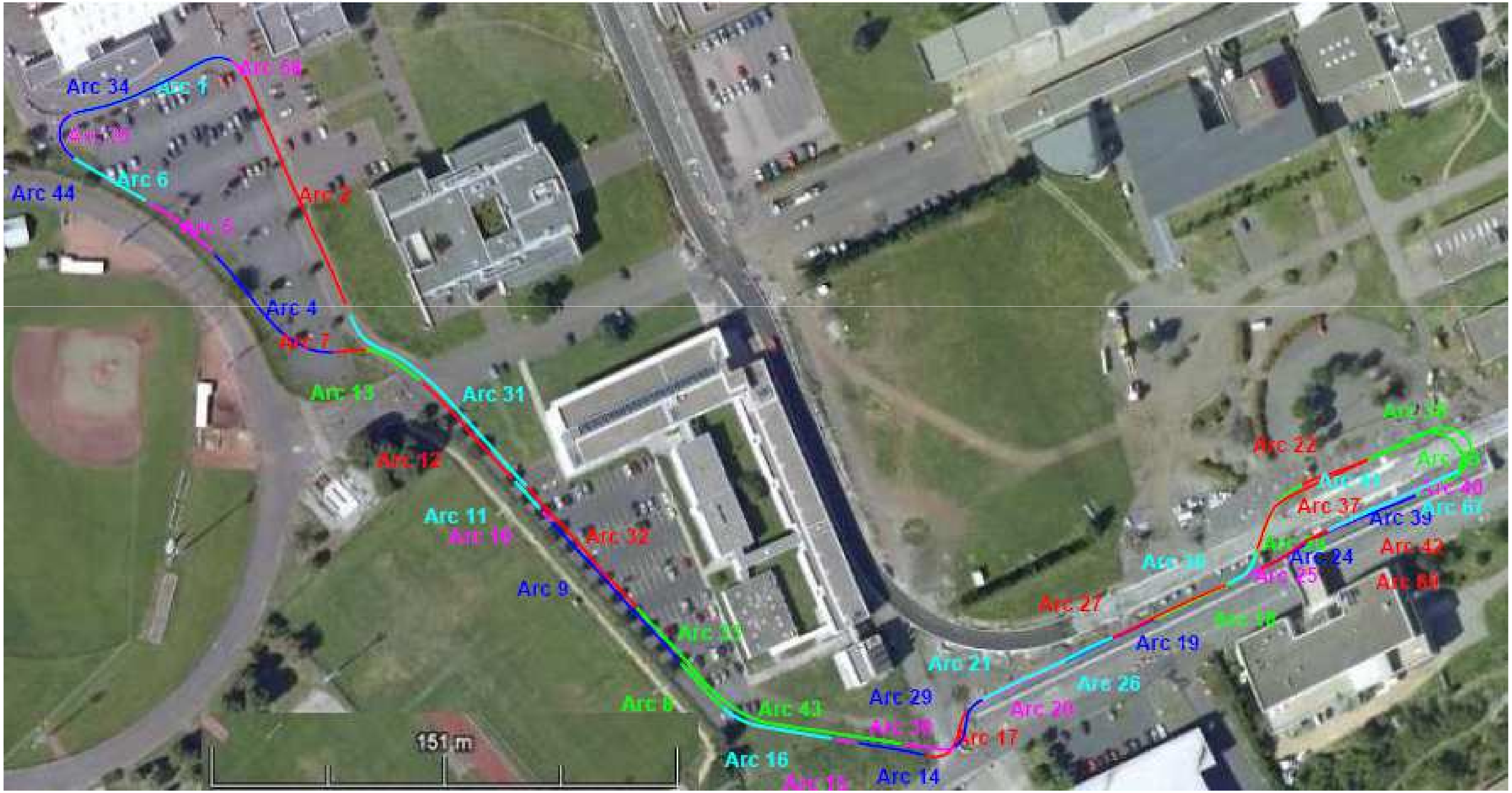
(y, θ) evaluation

Illustrations: Autonomous Taxi Robot using sensory memory

Loop 1200 m – 35 edges

Navigation 1700m (26 minutes, 1400 keys images, 54 edges)

AGV using visual memory



Illustrations: Autonomous Taxi Robot using sensory memory

Topological navigation using visual memory

Cityvip
Clermont-Fd 2008

Using vision only

Clermont-Ferrand
LASMEA-GRAVIR

Illustrations: COGIRO (Large volume parallel robot controlled by vision)

COGIRO Project → GIant Parallel RObot Control

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

Step 1: Study of small size Wire Driven Parallel Robot neglecting the weight of the wire from kinematics to dynamics

[IROS11]

Step 2: Developing new models for weighted wire parallel robot

[IROS12]

Step 3: Developing new control strategy for large size wire driven robot

Illustrations: COGIRO (Large volume parallel robot controlled by vision)

15 m x 11 m x 6 m (L x l x h)

Vision-Based Control of the CoGiRo prototype Using a Multiple-Camera Setup

Outline

Introduction

- *Applications*
- *Environment modeling*
- *Some potential solution*

Localization

- *Sensor technology*
- *Global Localization*
- *Local localization*

Navigation

- *Modeling*
- *Control*
- *Illustrations*

Conclusion

- *Current status*
- *Future*

Conclusion

Current status:

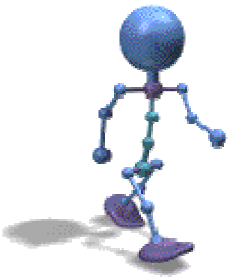
- **Many new products in terms of 3D points/3D pose estimation**
- **It is possible to work in 3D with 3D Pose (6D) Estimation/tracking in the loop**
- **It is possible using specific camera to estimate both pose and velocities (12D)**
- **Sensor networks enlarge the workspace**

Future

- **New version of Kinect should be able to improve the offer**
- **Development of sensor network should be done including time stamping and auto calibration abilities**
- **Generalization on the use of 12D for dynamic control application**
- **Data fusion between exteroceptive and proprioceptive sensors will allow to reach robustness**
- **Sensor based control approach must be commonly used**

Thanks for your attention

Any questions



http://www.irccyn.ec-nantes.fr/~martinet

Philippe.Martinet@irccyn.ec-nantes.fr