Nouveaux concepts de mobilité urbaine: retour sur l'expérience de CityMobil

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Outline

- CityMobil : objectifs
- Les démonstrateurs de CityMobil
- Les navettes Cybus à La Rochelle: description and défis techniques
- Performances et évaluations
- Conclusion & travaux futurs
The CityMobil project

**FP6 Project**

- **Project start:** May 1, 2006
- **Project duration:** 5 years
- **Coordinator:** TNO
- **No. of Partners:** 29
- **Project Budget:** 40 million Euros
- **EU funding:** 11 million Euros
- **Budget division:**
  - About 40% for demo’s
  - About 60% for R&D
The CityMobil project: objectives

- To achieve a more effective and sustainable organisation of urban transport by:
  - The development of advanced concepts for advanced road vehicles for passengers and goods.
  - The introduction of new tools for managing urban transport
  - Removing barriers in the way of large scale introduction of automated transport systems:
    - By bringing the implementation of automated transport in urban areas a major step forward
    - Through large and small scale demonstrations of Automated transport systems
CityMobil demonstrations

**Advanced bus**
- Castellon (ES)
- Heathrow (UK)
- Rome (I)

**PRT Cybercar**
- La Rochelle (F)

**Advanced city cars**
- Daventry (UK)
- Vantaa (FI)
- Trondheim (N)
- La Rochelle (F)
- Orta San Giulio (I)
Examples of advanced transport systems

Cybercars

Advanced Buses

Advanced city vehicles

Personal Rapid Transit
3 large scale implementations of advanced transport systems: city demonstrations

- Heathrow
- Rome
- Castellón
City demos: Heathrow

- Connects Business Parking with T5
- 3.9 km of single guideway
- 21 vehicles
- 3 stations
- 5min journey time

- Traverses 2 rivers and 7 roads
- Green belt land
- Negotiates aircraft surfaces
- Bridges in-ground services
- Conforms to T5 architecture
- Looks “Intended”
City demos: Heathrow
City Demos: Rome

A cybercar system that connects the car park with the entrance of the new Rome Exhibition buildings.
City Demos: Rome

- 29 passengers;
- Max speed: 24 km/h;
- Obstacle detection systems: laser scanner and bumper switches.
City Demos: Castellón

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City Demos: Castellón

City Mobil

Groupe de Travail inter GdR « Réseaux et Systèmes Électriques intelligents »

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Expected results of CityMobil

**General results:**

- A much better understanding of the possibilities of automated transport systems in cities
- An improved acceptance of advanced transport systems among the public as well as among authorities
- Less legal, administrative, operational and technological barriers for the implementation of advanced urban transport systems
- ... technical validation and evaluation of the systems
La Rochelle Small Demos
La Rochelle demo: objectives

- To test a real-life implementation of cybercars in an urban context
- To evaluate the system’s performance:
  - Technically
  - Transportation efficiency
  - Economically*
  - Energy consumption
- To evaluate users’ acceptance
La Rochelle demonstration

- The showcase motivated the City to host a demonstration of cybercars
- The City proposed an urban test site:
  - 2 km
  - 5 stations
  - Mixed traffic
  - 4 crossings with car traffic
  - Traffic priority given to cybercars (stop signs)
  - Infrastructure not to be equipped!
La Rochelle demonstration

- 2-3 INRIA’s CyBus platforms
- On-demand service as an “horizontal elevator”
- Speed limited to 15 Km/h
- An operator is always on-board (legal reasons)
- Demonstration ran between May and July 2011 and in November-December 2012 at INRIA
La Rochelle: site

Paris

La Rochelle

Old city centre

Electric boat line

Demo site

BRT line
La Rochelle: site

- Car-sharing station
- Electric boat stop
- Bike-sharing
- Museums area
- Conference Centre
- Technoforum (University) / BRT stop
- Cybertcars depot
INRIA’s CyBus vehicles

Capacity: 5 pax
Max. speed: 18 Km/h
Mass: 500 Kg

Front & rear LIDARs
Ultrasounds
IP cameras
Guidance: LIDAR-based SLAM
INRIA’s CyberGo vehicle

Capacity: 8 pax
Speed: 30 Km/h
Mass: 700 Kg

Sensors:
- 4 LIDARs guidance
- US
- Cameras
Stations

- Accessibility for elderly
- Vehicle call interface
- Wi-Fi network relay
- Users information on the booths:
  - Instructions
  - Usage conditions

Electricity for stations
- Solar energy not feasible
- Batteries recharged overnight from public lightning
Demonstration site constraints

Road narrowness = stations only on 1 side
Vehicle must drive forward & backwards
Cybercars Demonstration architecture

Communications
- ~200 m between stations
- Interference of trees
- Wifi routers and antennas were installed on 4.5 m poles
- Full Wi-Fi coverage from the depot to the last station (~1 Km)
Cybercars circulation scheme
Demonstration site constraints

Pedestrian area = limited speed
Demonstration site constraints

Intersections = cybercars priority crossing at limited speed
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Technical challenges of the navigation in dense urban areas
Challenges

- Environment mapping and localization in crowded areas:
  - GPS shortage, laser masking, vehicle « kidnapping »...
  - Fusion of GPS-IMU and Laser-based SLAMMOT

- Perception:
  - Obstacle detection and tracking
  - Behavior modeling: cognitive perception
    - Uncertain obstacle classification
  - Cooperative perception

- Precise docking:
  - GPS/SLAM-based: 10 cm error
  - Tomorrow:
    - Vision based docking (cf. AMARE project)?
    - Beacons detection and localization
Challenges

- Path planning in an unknown dynamic environment:
  - Navigation strategy
  - Planned paths vs. Reactive planning
  - Overtaking strategies (obstacles types, sizes and speeds)

- Communication in dense and noisy areas
  - Technology
  - Centralized vs. Decentralized

- Optimization of the demand: fleet management
  - Vehicle management System (VMS) based on a new V2I COM architecture

- Task planning and supervising (scheduling)

- Fault tolerance
  - Sensors, Processors, Communication bus
  - Distributed architecture: Redundancy
Global architecture of the CYBUS
Sensors configuration for obstacle detection, localization and mapping
Precise Localization System Solution

1. Laser based SLAM For Providing an Accurate Map and Position
2. Fuse With IMU Data Using EKF For Improving Localization precision
3. Fusion of GPS/SLAM for a geo-referenced localization
New embedded system

- Simple distributed architecture
- Based on DSPIC and Syndex software:
  - Tasks (re-)scheduling
  - Handles redundancy and fault tolerance
Communication architecture

New architecture: clearly separates the layers

- Discovery services: Avahi / Bonjour
- Embedded communication libraries: dohc / chassis / cables
- Logic layer: RTMaps
Communication and the VMS

- Using high frequency wifi
- Dynamic IPv6 network and routing at the kernel level using Batman
- Standards: IPv6/CALM
- Operates on layer 2:
  - Allow IPv4, IPv6, DHCP...
  - Nodes do not need an IP
  - Based on connection quality
The VMS

- Knows all the vehicles
- Aware of the static map
- Takes decision when needed
Vehicles Interactions

Definition:
- Take into account all vehicles parameters in the decision process

Centralized vs. Decentralized
- Centralized: VMS based V2I COM
  - Global environment modeling
  - Optimized
  - Sensible to COM outages

- Decentralized: V2V based
  - Local model
  - Non-optimal
  - COM outages

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Objectives:

- Ensure optimal system planning:
  - Fleet management for the transportation service
- Handle complex situations
- Handle conflicts and blockages

Example: static obstacle avoidance
- Design & development of 2 techniques for vehicle avoidance maneuvers:
  1. Planning and Nonlinear Adaptive Control
  2. Use of elastic bands for autonomous local guidance
Planning and Nonlinear Adaptive Control

- Developed for both CityMobil and HAVEit projects!
  - (published in IEEE ITSC 2011 – Washington)
The overtaking maneuver involving two vehicles is established as a three-phase maneuver.

Our approach: Consecutive tracking of reference virtual points $R_1$, $R_2$, $R_3$ situated at desired distances from the overtaken vehicle with a virtual reference point ‘L’ attached to the overtaking vehicle.
Mathematical model for the 1st phase

\[
\begin{bmatrix}
\dot{e}_x \\
\dot{e}_y \\
\dot{e}_\theta
\end{bmatrix} =
\begin{bmatrix}
\cos e_\theta & 0 & -L_2 \sin e_\theta \\
\sin e_\theta & 0 & L_2 \cos e_\theta \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
v_x \\
0 \\
\omega
\end{bmatrix} -
\begin{bmatrix}
1 & 0 & -L_{1n} \\
0 & 0 & -L_{1t} \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
v_{Rx} \\
0 \\
0
\end{bmatrix}
\]

\[
\alpha = a \tan\left(\frac{L_2 \omega}{v_x}\right)
\]

\(\alpha\) – front wheel steering angle

\((e_x, e_y)\) – coordinates of the reference point L in \(R_1x_1y_1\);

\((L_{1t}, L_{1n})\) – coordinates of the reference R1 in \(A1xy\) linked to the overtaken vehicle.
**Planning and Nonlinear Adaptive Control**

- **Trajectory planning**
  
  Generation of smooth trajectories for point-to-point motion for every phase in terms of the posture errors $(e_x, e_y)$ with respect to the moving reference frames $R_i^xR_i^yR_i$ which are rigidly linked to the overtaken vehicle.

  
  \[
  e_x^d(t) = a_{0x} + a_{1x}(t-t_0) + a_{2x}(t-t_0)^2 + a_{3x}(t-t_0)^3 \\
  e_y^d(t) = a_{0y} + a_{1y}(t-t_0) + a_{2y}(t-t_0)^2 + a_{3y}(t-t_0)^3
  \]

  
  **Initial conditions**

  \[
  \begin{align*}
  e_x^d(t_0) &= e_{x0} \\
  e_y^d(t_0) &= e_{y0} \\
  \dot{e}_x^d(t_0) &= \dot{e}_{x0} \\
  \dot{e}_y^d(t_0) &= \dot{e}_{y0}
  \end{align*}
  \]

  **Final conditions**

  \[
  \begin{align*}
  e_x^d(t_f) &= 0 \\
  e_y^d(t_f) &= 0 \\
  \dot{e}_x^d(t_f) &= \Delta v_{Rx}(t_f) \\
  \dot{e}_y^d(t_f) &= 0
  \end{align*}
  \]
Planning and Nonlinear Adaptive Control

- First validation with simulated data
- Second validation with the Cybus
Planning and Nonlinear Adaptive Control

- **Problems:**
  - Needs the exact vehicle dimensions (OK for communicating vehicles!)
  - Needs an accurate position and speed estimation (measurement)
  - What if there are several « hidden » vehicles ?
  - What if the vehicle moves again ?
  - What if a ‘hostile’ obstacle threatens the vehicle ?
  - ...

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**Elastic (bubbles) bands**

- **Elastic bands** are proposed to close the gap between global path planning and real-time sensor-based robot control.

- An elastic band is a *deformable collision-free path*. Subjected to artificial forces, the elastic band deforms in real time to a short and smooth path that maintains clearance from the obstacles.

- While providing a tight connection between the robot and its environment, the elastic band preserves the global nature of the planned path.

- Adapted to holonomic (non-) vehicles.

[Khatib M. and Jaouni H., 1996]
[Quinlan and Khatib O.]
Elastic (bubbles) bands

- Reference trajectory:
  - Registered path or;
  - Planned trajectory

Figure: Willow Garage implementation

Figure: SIVIC simulator (INRIA)

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Scenarios demonstrations
Extension scenarios

Scenario 1

Scenario 2
Extension scenarios

Scenario 3

Scenario 4
Extension scenarios

Scenario 5

Scenario 6

CM General Assembly
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System evaluation
Users acceptance (1/2)

6 indicators evaluated:

- Ease of use ranking (in a rate from 5 to 1): 3.8
- User willingness to pay: 0.6€
- Info availability,
- info comprehensibility,
- perception of safety,
- fear of attack
STATISTICS

899 Passengers (200 interviews)

GENDER

- M: 51%
- F: 49%

AGE

- < 16 years: 9%
- 16 - 25 years: 27%
- 26 - 35 years: 15%
- 36 - 45 years: 10%
- 46 - 60 years: 10%
- > 60 years: 31%
User acceptance (2/2)

- Information avail.
- Information compr.
- Perception of safety
- Fear of attack
Transportation results

- Total operation time: 73 days
- Total Veh•Km: 343,3
- Total vehicle trips: >1700
- Total passengers: >1000

- Average vehicle occupancy: 33%
- Average journey time per OD pair: 1’ 15’’ ÷ 2’ 40’’
- Average waiting time: 2’ 30’’
- Effective system capacity: 100 pax/h
Environment

- Daily consumption: 1.95 kWh
- Energy efficiency: 0.38 kWh/pax·km
Technological success

- Failure rate of the ‘control’ indicator: 7%
- Mean time between failures: 14 days
Origin of users

They come from...

- La Rochelle
- Agglomération de La Rochelle
- En Charente Maritime
- France, Etranger

They came...

- Specialement
- De passage

CM General Assembly

23%

77%
How did you hear about the system?

- 57% from Television, radio
- 22% from Internet
- 10% from Office du tourisme
- 9% from Bouche à oreilles
- 1% from Presse
- 1% from En passant devant
Advantages

- Green: 34%
- Quiet: 20%
- Automated: 14%
- Other (modern, available..): 14%
- Economique: 8%
- Practical: 10%
Disadvantages

- Low speed: 42%
- Small size: 23%
- Other: 9%
- Imposed circuit: 6%
- Waiting time: 3%
- Short travel: 8%
- Pas sûr: 3%
- Confort: 6%
Security and safety

Do you feel safe?

- oui: 27%
- non: 73%

Are you afraid of having an accident?

- oui: 35%
- non: 65%
Could this transport system be:

Adapted to the city?
- oui: 94%
- non: 6%

Generalized?
- oui: 93%
- non: 7%
Are you willing to pay?

- Oui: 64%
- Non: 36%

- <2€: 43%
- >2€: 52%
- Carte Yélo: 5%
Vandalism
Accident
Conclusion & Future work

1. Technical perspectives

- Extended perception
  - Allows complex situations handling
  - Allows more intelligent overtaking
    - Example: overtaking of stopped aligned vehicles
    - Example: barricades, crossing pedestrians...
  - Handles non communicating vehicles
- Introduction of vision technology
  - Fusion & redundancy
Conclusion & Future work

- Deployment of advanced communications
  - New « communication boxes » under design

- Achieve sensor-based docking:
  - GPS based
  - Vision based (AMARE project)
  - Magnets
Conclusion & Future work

- Test new scenarios with multiple vehicles / multiple platforms
  - Compliance & genericity

- Introduce/study « tricky » situations:
  - moving obstacles
  - Approaching ‘hostile’ obstacle
  - ...

- Introduce platooning

- Autonomy vs. VMS based architecture
2. General perspectives

- At INRIA: Permanent demonstrator / service in 2012 (Rocquencourt)
- In France: Mobilité 2015 / SYSMO 2015
- Europe: CityMobil-2
  - Address technical and legal issues
  - Acceptability and certification
Thank you!
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On demandera un nouveau système de transport à La Rochelle.

CityMobil Presentation