“e-Motion” Project-Team
« Geometry and Probability for motion and action »

INRIA Grenoble Rhône-Alpes
&
Laboratory of Informatics of Grenoble (LIG)

Scientific leader : Christian LAUGIER (DR1 INRIA)

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Scientific challenge

• Overall challenge

Robots in Human Environments

• Main Motivations

✓ Important socio-economic perspectives  => Transport, Aging society, Medical care & Rehabilitation, Human assistance, Intelligent home ...

✓ Increasing interest of industry  => Automotive industry, Robots, Health sector, Services ...

✓ Challenging research topics  => Dynamic world, Robust perception, Safety, Human Aware Motion, Complex Human-Robot interactions ...

✓ Robotics state-of-the-art & Progress in ICT Technologies (computers, sensors, micro-nano technologies, energy ...) make this challenge potentially reachable
**Required breakthroughs & Approach**

- **Required breakthroughs**
  - Motion autonomy in Open & Dynamic environments
  - Safe & Understandable Human-Robot interactions

- **Main difficulties**
  - World & Task complexity
  - Reactivity & Real-time constraints
  - Incompleteness & Uncertainty
  - Human in the loop

- **Scientific approach**
  - Revisit traditional approaches not fully adapted to the processing of Human environments
  - Design new models & algorithms for “Perception & Decision & Action & Interaction” in Complex & Highly Dynamic environments populated by Human beings
  - Focus on Robustness & Efficiency & Safety

**Our approach:** Combining Geometrical & Probabilistic approaches
Outline of the Scientific Project

• Scientific positioning
  ✓ Field of Probabilistic Robotics & Cognitive Systems
  ✓ Pioneer work on Bayesian Programming & Motion Planning in dynamic environments

• Research objectives
  ✓ Dynamic world Perception & Understanding
  ✓ Motion planning & Autonomous Navigation in the Real World
  ✓ Bayesian approach to Cognitive Systems

Main Achievements

✓ Technological transfers with our start-up “Probayes” (ProBT library, BOF software)
  Industrial applications in Robotics (Toyota, Denso, Hitachi) and in some other domains such as
  Finance, Plant maintenance, Video games, or Threat evaluation

✓ Perception & Interpretation of dynamic environments using Sensor Fusion and Bayesian
  Reasoning. Application to probabilistic “Risk Assessment” (in particular with Toyota)

✓ Concepts of PMP & ICS for Motion Planning in Dynamic environments

✓ Bayesian models for some Human SMS (e.g. perception of shape from motion, colliculus)
Robotics Experimental Platform

Parkview

Commercialized by Robosoft

Cycab & Simulator

Commercialized by Bluebotics

Koala

Autonomous Wheelchairs

Industrial Experimental Vehicles
(soon a Toyota Prius vehicle)

Christian LAUGIER – e-Motion project-team
**Personnel**

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- **Permanent staff (6.5)**
  - 3 INRIA Researchers: Christian Laugier (DR1), Thierry Fraichard (CR1), Agostino Martinelli (CR1)
  - 1 CNRS Researchers: Pierre Bessiere (DR2)
  - 2 Associate Professors: Olivier Aycard (UJF), Anne Spalanzani (UPMF)
  - 0.5 Permanent Engineer: Amaury Negre (CNRS, shared with EPI Prima)
  - 2 Leasing: Emmanuel Mazer (CEO Probayes), Sepanta Sekhavat (Iran)

- **Attractivity evidences**
  - Recruitment of Agostino Martinelli in 2006 (Italian, previously Ass. Researcher at EPFL)
  - Average of 2 Visitors & Invited professors per year (from Spain, Germany, USA, Mexico, Israel, Singapore)
Research Objectives

- **Objective 1**: Dynamic world Perception & Understanding
  ~ 50 % activity of e-Motion

- **Objective 2**: Motion planning & Autonomous navigation in the real world

- **Objective 3**: Bayesian approach to Cognitive Systems
The addressed problem

Moving safely amidst Stationary & Moving obstacles (vehicles, pedestrians ...) in Open & Dynamic environments

- **Continuously changing environment**
  - Continuous world modeling using sensors
  - Space & Time have to be considered
  - Real-time processing is required

- **Sensed Stationary & Moving obstacles**
  - SLAM + DATMO
  - Uncertainty is a key issue (perception, localization, tracking ...)

- **Complex partly known environments**
  - Most probable world changes have to be predicted!
  - Iterative safe navigation decisions (based on world states estimation & prediction)
Considerable research material exists on SLAM, Detection & Tracking, but robustness is still an issue!

Few contributions on Prediction & Risk assessment

Focus on Open & Highly Dynamic environments

=> Robustness & Efficiency issues

Three main topics

1. Robust Detection & Tracking  => Sensor Fusion + Grid based approach in space (OG) & Space/Velocity (BOF) + Towards a unique Detection & Tracking process


3. Prediction & Risk assessment  => Prediction of the future behavior of the observed entities + Probabilistic Risk assessment
Main Topics & Achievements
6 PhD, 1 Book, 15 journal papers

Robust Detection & Tracking
[Burlet 07][Coue 05]
(coop. Denso, Toyota, Daimler)

Simultaneous calibration of Odometry & Bearing sensor
[Martinelli 08]
(Coop. ETH Zurich)

Vision based Detection & TTC
[Braillon 08][Negre 09]
(Coop. Prima)

Dense IBEO 3D data

World change prediction
[Vasquez 07]
(coop. ETH Zurich)

Risk assessment using GP
[Tay PhD Thesis]
(coop. Toyota)

Efficient 3D Multi-resolution Mapping using “Tensor maps”
[Yguel PhD Thesis]
(coop. Perception, Ibeo)
**Laser based Multi-Objects Detection & Tracking**

“PreVent” EU project  [Burlet, Vu, Aycard 07-08]

• **Grid-based Obstacles Detection**

  - Sensed moving obstacle
  - Ego vehicle position
  - OG: 160m x 200m
  - Resolution 20cm x 20cm
  - Potentially Free Space (“Empty” cells)
  - Dynamic Obstacles
  - Unknown Space
  - Static Obstacles

• **Multi-Objects Tracking**

  ✓ **Mapping & localization:** Scan matching

  ✓ **Data Association:** Multiple Hypotheses (for n time steps)

  ✓ **Filtering:** Interacting Multiple Models

  *Inspired from [Blakman 98] (radar) & [Wang 04] (laser + ICP)*

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Experimental validation

“PreVent” EU project, Versailles demo 2007 (Daimler-Chrysler & Ibeo test vehicle)

Application:
• Pre-fire & Braking

Sensors:
• Two short range radars
• A laser scanner ALASCA

Actuators:
• Electrical belt pre-tensioning
• Automatic braking

Computational time ~ 10 ms

Multiple Hypothesis Tracking of Moving Objects using Grid-based Fusion

Julien Burlet, Trung-Dung Vu, Olivier Aycard
LIG & INRIA Rhône Alpes, France

Contact: Olivier.Aycard@inrialpes.fr

Also tested on a truck Volvo / Ibeo
Currently under testing on a Volkswagen / Ibeo demonstrator
Bayesian Sensor Fusion for “Dynamic Perception”

“Bayesian Occupation Filter paradigm (BOF)”

Patented by INRIA & Probayes, Commercialized by Probayes

- Continuous Dynamic environment modelling
- Grid approach based on Bayesian Filtering
- Estimates Probability of Occupation & Velocity of each cell in a 4D-grid
- Application to Obstacle Detection & Tracking + Dynamic Scene Interpretation

=> More robust Sensing & Tracking + More robust to Temporary Occultation

BOF

Sensed moving obstacle

\[ \text{Occupancy grid} \]

\[ \text{Unobservable space ("shadow" of the obstacle)} \]

\[ \text{Occupied space} \]

\[ \text{Free space} \]

\[ \text{Prediction} \]

\[ \text{Estimation} \]

\[ P\left( O_{z=\text{occ}} \mid z \right) = \begin{cases} x, y, 0, 0 \text{ and } z=(5, 2, 0, 0) \end{cases} \]
Robustness to Temporary Occultation

Tracking + Conservative anticipation [Coué & al IJRR 05]

Specification
- Variables:
  - $V_k$, $V_{k-1}$: controlled velocities
  - $Z^{0:k}$: sensor observations
  - $G^k$: occupancy grid

- Parametric forms:
  - $P(G^k | Z^{0:k})$: BOF estimation
  - $P(V_k | V_{k-1} G^k)$: Given or learned

Inference
- $P(V^k | Z^{0:k}, V^{k-1})$

Description

Thanks to the prediction capability of the BOF, the Autonomous Vehicle “anticipates” the behavior of the pedestrian and brakes (even if the pedestrian is temporarily hidden by the parked vehicle)
Application to Robust Detection & Tracking

- Data association is performed as lately as possible
- Tracking more robust to Perception errors (false positives & negatives) & Temporary occlusions

Successfully tested in real traffic conditions:
- TOYOTA
- DENSO Lidar
- Current tests with IBEO Lidar
World changes Prediction

[Vasquez & al 05, 06, 07, 08]

- Risk assessment requires to both *Estimate the current world state* & *Predict the most likely evolution of the dynamic environment*

- Objects motions are driven by “*Intentions*” and “*Dynamic Behaviors*” => *Goal + Motion model*

- Goal & Motion models are not known nor directly observable …. But “*Typical Behaviors & Motion Patterns*” can be learned through observations

Our Approach :
*Continuous “Learn & Predict” using GHMM & Topological maps (SON)*

Experiments using Leeds parking data
Risk assessment for next few seconds

- **Behavior Prediction (HMM)**: Observations + Behavior models → Prediction
- **Risk Assessment (GP)**: Behavior belief table for each vehicle in the scene + Road geometry (GIS) + Own vehicle trajectory to evaluate → Evaluation → Collision probability for own vehicle

- High-level Behavior prediction for other vehicles (Observations + HMM)
- Risk estimation (Gaussian Process)

Cooperation Toyota & Probayes

[Tay Thesis 09]
Research Objectives

- **Objective 1: Dynamic world Perception & Understanding**

- **Objective 2: Motion planning & Autonomous navigation in the real world**
  ~25% activity of e-Motion

- **Objective 3: Bayesian approach to Cognitive Systems**
**Problem statement**

**Objective:**
Goal oriented & Safe navigation in open & highly dynamic environments

**New constraints:**
- Upper-bounded decision time
- System’s dynamics
- Moving Objects’ future behavior
- Look-ahead
- Uncertainty

**Positioning:**
- Few contributions in the literature
- Taking into account all the new constraints coming from Open & Dynamic environments
- A new framework based on iterative safe motion decisions
- Focus on motion Safety
A new framework for MP in Dynamic environments

1 HDR, 1 PhD, 4 Journal papers

[Fraichard 04] [Petti 06] [Martinez 08]

• Partial Motion Planning (PMP)

Repeat until goal is reached
1. Get model of the future (observation & prediction)
2. Built tree of partial motions towards the goal
3. When time $\delta_c$ is over, Return “best partial motion” (e.g. closest & safest)

• Inevitable Collision States (ICS)

⇒ Avoiding instantaneous collision is not enough!
We also have to avoid states leading to “Inevitable Collisions” in the near future
⇒ Doing nothing may also be dangerous!

Key requirement: Model of the future (cf. Objective #1)
Integrating Probabilistic Uncertainty in PMP

Motion Planning combined with Risk assessment

- Detection & Tracking of obstacles
- Risk assessment based on behaviors prediction *(HMM & Gaussian Process)*
- RRT search *(previously explored states are updated on-line with new observations)*

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Research Objectives

- **Objective 1:** Dynamic world Perception & Understanding
- **Objective 2:** Motion planning & Autonomous navigation in the real world
- **Objective 3:** Bayesian approach to Cognitive Systems
  ~25% activity of e-Motion
Positioning

• Basic assumption
  ✓ Probability is an alternative to logic to reason with incomplete & uncertain knowledge
  ✓ Probability is an emerging cognitive paradigm for “perception, action, decision and learning”
  ✓ This framework can be used for modeling both Natural & Artificial systems

• Research topics & Achievements
  ✓ Formalization of Bayesian Probability => Bayesian Programming [Bessiere 97]
  ✓ Automatization of probabilistic inference & Development of industrial applications
    => ProBT inference engine (commercialized by ProBayes SAS)
  ✓ Bayesian robot programming
  ✓ Bayesian modeling of living systems

• Working context
  ✓ Probayes SAS
  ✓ European projects BIBA & BACS
  ✓ Strong cooperation with LLPA Collège de France (A. Berthoz & J. Droulez)
Main Topics & Achievements
6 PhD, 1 Book, 9 journal papers (Robotics & Neurosciences)

Robots

Prey & Predator scenario

Action selection & Attention focusing
[LeHy 07] [Dangauthier 08]

Bayesian learning

Brain controlled wheelchair [Rebsamen 09]
(coop. NUS Singapore)

Living systems

Human Perception of Shape from Motion
[Colas 06] (coop. LPPA)

Bayesian models of Superior Colliculus
[Colas et al. 09] (coop. LPPA)

Sensory-motor systems & Handwriting
[E. Gillet PhD Thesis] (coop. LPN)

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Human perception of shape from motion

**Problem addressed**
- **Inverse problem** => *The geometry produces the stimulus*
- **Ambiguous** => *Same optical flow for different physical situations*
- **Uncertain** => *Ocular defaults*
- **Brain interpretation** => *Relies on prior hypotheses (e.g. convexity, rigidity ...)*

**Bayesian model for the perception of moving planes** (coop. J. Droulez LPPA)

The same Bayesian model has produced identical perception results than 5 psychophysics experiments (for the perception of planes & motions)
Objectives for the next four years (1)

- Continuing to work on the three current research themes of e-Motion

- Improving our key technologies, with the objective to transfer some of them to the automotive industry. Context: ADT ArosDyn & Toyota & Probayes

- Experimental tests in real traffic conditions => Toyota Prius experimental vehicle


- More emphasis in objective 3 on the study of living systems => Cooperation with our neurophysiologist partners

![Toyota Prius (future experimental vehicle)](image1)
![Autonomous Wheelchair](image2)
Objectives for the next four years (2)

• Objective 1: Dynamic world Perception & Understanding

✓ Improved grid-based Bayesian filtering => Models + GPU + SOC with CEA

✓ Robust Detection & Tracking => Specialized fusion based Detectors + Better integration of Detection & Tracking (using classification & models)

✓ Accurate and Efficient Localization & Mapping => Efficient 3D multi-resolution models & Hybrid maps

✓ Risk assessment => Generalization to more complex traffic scenes + Learning behaviors + Integration with MP (objective 2)

Urban traffic situations

Preliminary results using Data-Driven MCMC for Spatial-Temporal search [Vu 09]
Objectives for the next four years (3)

• Objective 2 : Motion Planning & Autonomous Navigation in Real World
  ✓ Probabilistic ICS => Taking into account uncertainty
  ✓ Coupling PMP & ICS => Focus on safety guarantees
  ✓ Coupling PMP & Risk assessment => Real sensor & GIS data + Risk factor in PMP

• Objective 3 : Bayesian approach to Cognitive Systems
  ✓ Bayesian robot programming => Focus on modeling & learning sensory-motor skills
  ✓ More emphasis on Bayesian modeling of Living systems => Behavioral level & Central nervous system (new prospective issue)
Cooperation

• **Cooperation inside INRIA**
  – Robotics: *Imara* (common PhD students), *Lagadic, Arobas*, more recently *Coprin*
  – Other domains: *Prima* (common PhD students), *Perception*, more recently *Galaad*
  – Future AEN “Personally Assisted Living”

• **International cooperation**
  – Large participation to European projects (*NOE, IP, Streps*)
  – Formal cooperation agreements (Singapore, Mexico)
  – Coordinator *ICT-Asia NOE on ITS* (Singapore, Korea, China, Japan, France)

• **Industrial cooperation**
  – 4 Start-up (*ITMI, Getris Image, Aleph Technologies, Probayes*)
  – Long-term industrial collaborations with *Probayes, Toyota, Denso*
Knowledge dissemination

• Software
  ✓ ProBT & BOF (patented), Robot simulator, ColDetect, Markov models toolbox

• Valorization
  ✓ Start-up Probayes & Several common R&D projects (Toyota, Denso, Hitachi ...)
  ✓ ProBT inference engine & BOF => Used in several industrial applications (Car safety, Finance, Plant maintenance, Video games, Threat evaluation)

• Teaching
  ✓ Engineer schools, Master, International Tutorials, Summer schools (SSIR)

• Visibility
  ✓ General chair & Program chair of some major international conference (IROS’97, IROS’00, IROS’02, IROS’08, FSR’07, IV’06)
  ✓ Organization of focuses workshops + Publications of Books & Journal special issues (STAR, IJRR, JFR, IEEE ITS, IJVAS)
  ✓ Invited talks & Keynotes (SRG’04 Singapore, ICARCV’08, FSR’09, ISRR’07 ...)
  ✓ Steering committees (IROS, IEEE TC on ITS), Editorial boards (IEEE TRO, IEEE ITS, RIA ...), NOE coordination (ICT-Asia)
# Publications

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(*) HDR Habilitation à diriger des Recherches
(**) Conference with a program committee
+ 9 invited talks

**Remark:** The four first journals of the list are considered as journals of rank A by the GDR Robotique.

1. International Journal of Robotics Research (IJRR, IF=1.315) (A)
2. IEEE Transactions on Robotics (IEEE TRR, IF=1.976) (A)
3. IEEE Transactions on Intelligent Transportation Systems (IEEE ITS, IF=1.689) (A)
4. Autonomous Robots (IF=1.413) (3)
5. Field Robotics (IF=0.960) (A)
6. Robotics and Autonomous Systems (RAS, IF=0.633) (3)
7. Advanced Robotics (IF=0.304) (4)

**Other journals:** Biological Cybernetics, Machine Vision & Applications, Medical Image Analysis, RIA, Autonomous Vehicles ...

**Other conferences:** NIPS, World congress of Psychophysiology, CogSys, SYROCO, ICCV, ICARCV, RFIA, European Robotics Symposium, ...

Christian LAUGIER – e-Motion project-team
Thank You!
Any questions?

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