Situation Awareness & Collision Risk Assessment to improve Driving Safety

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- INRIA, Toyota, Probayes, Renault -

Keynote talk at IEEE/RSJ IROS 2011 Workshop on “Perception and Navigation for Autonomous Vehicles in Human Environments”
Structure of the talk

1. Context, State of the art, and current Challenges
2. Bayesian Perception
3. Prediction & Collision risk assessment
4. Roads Intersection Safety
5. Conclusion & Perspectives
Socio-Economic & Technical context

• Nowadays, Human Society is no more accepting the incredible socio-economic cost of traffic accidents!

1.2 million fatalities / year in the world !!!!
- USA (2007) : Accident every 5s =>41 059 killed & 2.6 million injured .... Similar numbers in Europe
- France (2008): 37 million vehicles & 4443 fatalities (double number in the past years)

• Driving Safety is now becoming a major issue for both governments (regulations) and automotive industry (technology)

• Thanks to recent advances in the field of Robotics & ICT technologies, Smart Cars & ITS are gradually becoming a reality

=> Driving assistance & Autonomous driving, Passive & Active Safety systems, V2V & I2V communications, Green technologies ...
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- But a real deployment of these technologies, requires first that Robustness & Safety, Human-Vehicle Interaction, and Legal issues have to be more deeply addressed!
Car technology is almost ready for Driving Assistance & Fully Autonomous Driving

Steering by wire
Brake by wire
Shift by wire

Virtual dash-board
Modern “wheel”

Navigation system
Driving assistance (speed, ABS, ESB ...)

Wireless Communication
Speech Recognition & Synthesis

Radar, Cameras, Night Vision, Various sensors, Parking assistance
.... Cost decreasing & Efficiency increasing (future mass production, SOC, embedded systems ...) !!!!
Autonomous Vehicles – State of the art (1)

- An EU driven concept since the 90’s: “Cybercars”
  - Autonomous Self Service **Urban & Green** Vehicles
  - Numerous R&D projects in Europe during the past 20 years
  - Several European cities involved
  - Some commercial products already exist for protected areas (e.g. airports, amusement parks ...), e.g. Robosoft, Get2There ...
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Several early large scale public experiments in Europe

Floriade 2002 (Amsterdam)

Shanghai public demo 2007 (Inria cooperation, EU FP7 project)
Fully Autonomous Driving

- More than 20 years of research, for both Off-road & Road Vehicles
- Significant recent steps towards fully autonomous driving (partly pushed forward by events such as DARPA Grand & Urban Challenges)
- Fully Autonomous driving is gradually becoming a reality, for both the Technical & Legal point of views !!!

June 22, 2011: Nevada passes Law Authorizing Driverless Cars (Rules & Regulations to be defined by DOT)
Autonomous Vehicles – State of the art (2)

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- Some major recent events

2007 Darpa Urban Challenge: 97 km, 50 manned & unmanned vehicles, 35 teams, 11 qualified, 6 finished the race

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2010 VIAC Intercontinental Autonomous Challenge: 13,000 km covered, 3 months race, leading vehicle + followers => See last IEEE RAM issue

2011 Google’s Car: A fleet of 6 automated Toyota Priuses, 140,000 miles covered on California roads with occasional human interventions
Autonomous Vehicles – Current Limitations

Current Autonomous vehicles are able to exhibit quite impressive skills .... BUT they are not yet fully adapted to human environments and they are often Unsafe!

=> DARPA Grand Challenge 2004
✓ Significant step towards Motion Autonomy
✓ But still some “Uncontrolled Behaviors” !!!!

=> URBAN Challenge 2007
✓ A large step towards road environments
✓ But still some accidents, even at low speed  !!!

Some technologies are almost ready for use in some restricted and/or protected public areas ..... BUT

✓ Fully open environments are still beyond the state of the art
✓ Safety is still not guaranteed
✓ Too many costly sensors are still required
Technologies to be improved

- **Situation awareness & Risk assessment**

  - **Dynamicity & Uncertainty**
    -> Space & Time + Probabilities
  - **Interpretation ambiguities**
    -> History, context, behaviors ...
  - **Prediction of future states**
    -> Avoiding future collisions !!

- **Share driving decisions & Safe interaction with human beings**

  But ... Human drivers is a potential danger for himself (inattention, wrong reflexes) !
  -> Monitoring & Interpreting driver actions is mandatory

Human beings are unbeatable in taking decisions in complex situations

Technology is better for “simple” but “fast” control decisions (ABS, ESP ...)
Outline of our approach – Two key technologies

Bayesian Perception

- Monitor the traffic environment using on-board sensors (Stereo Vision, Lidars, IMU, GPS, Odometry)
- Perform data fusion of multiple sensors by means of “Bayesian Occupancy Filtering (BOF)” => Patent INRIA-Probayes
- Process dynamic scenes in real time to Detect & Track multiple moving objects (BOF + FCTA)

Prediction & Collision Risk Assessment

- Predict scene changes & Evaluate Collision Risks using stochastic variables, HMM and Gaussian Process (GP) => Patent INRIA-Toyota-Probayes
- Prevent future collisions: Alert the driver and/or activate Automated braking and steering
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Bayesian Occupancy Filter – Improving sensing robustness

Patented by INRIA & Probayes – Commercialized by Probayes [Coué & Laugier IJRR 05]

Bayesian Occupancy Filter (BOF)

- Continuous Dynamic environment modelling using one or several sensors
- Grid approach based on Bayesian Filtering
- Estimates at each time step the Occupation & Velocity probabilities for each cell in a “Space-Velocity” grid
- Computation performed using probabilistic Sensor & Dynamic models

=> More robust to Sensing errors & Temporary occultation
=> Designed for Sensor Fusion & Parallel processing

\[
P(O_c^t \land A^t | z_1 \ldots z_3)\]

Occupancy probability
Velocity probability

\begin{align*}
\text{Prediction} & : P(O_c^t \land A^t) \\
\text{Estimation} & : P(O_c^t \land A^t | z')
\end{align*}

Moving object
Stationary objects
Concealed space ("shadow" of the obstacle)
Free space
Occupied space (obstacle)

\(P(O_c = \text{occ} | z_1 z_2 z_3)\)

Baysian Occupancy Filter (BOF)
Conservative prediction using the BOF
Application to Collision Anticipation (tracking + conservative hypotheses)

Autonomous Vehicle (Cycab)  Parked Vehicle (occultation)

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

- Data association is performed as lately as possible
- More robust to Perception errors & Temporary occlusions

Fast Clustering and Tracking Algorithm (FCTA)

Successfully tested in real traffic conditions using industrial datasets (Toyota, Denso)
Experimentations performed with the INRIA Lexus Platform

Experimentations performed with the INRIA Lexus Platform

Inertial sensor / GPS Xsens MTi-G
Dell computer + GPU + SSD memory

Stereo camera TYZX

2 Lidars IBEO Lux

Toya Lexus LS600h

GPS track example
(Using Open Street Map)
**Bayesian Sensor Fusion – Stereo Vision component**

From camera:

- Matching / Pixels classification (Road/Obstacle)

Stereo processor:

- U-disparity projections

Stereo sensor model:

- U-disparity grid computation
- Remap to Cartesian Grid

6 ms for 500 x 312 pixels and 52 disparity values

Left image:

- “obstacle” u-disparity
- “road” u-disparity
- Occupancy grid from u-disparity

U-disparity Occupancy Grid is superimposed on the camera image
**Sensor Fusion experiment:** **Stereo + 2 Lidars**

Front view from left camera

Fusion result using BOF

OG from left Lidar  
OG from right Lidar  
OG from Stereo

[Perrollaz et al 10] [Paromtchik et al 10]
Some experimental Sensor Fusion results

Pedestrian walking

Bus & Traffic sign

Cars on highway

Movie
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Collision Risk Assessment – Problem statement

Behavior Prediction + Probabilistic Risk Assessment

Consistent Prediction & Risk Assessment requires to reason about:

- History of obstacles Positions & Velocities \((\text{perception or communications})\)
- Obstacles expected Behaviors e.g. turning, overtaking, crossing ...
- Road geometry e.g. lanes, curves, intersections … using GIS

TTC-based crash warning is \textbf{not sufficient}!
1. **Driving Behavior Modeling & Learning**
   Modeling behaviors using x-HMM + Learning

2. **Driving Behavior Recognition**
   Estimate the probability distribution of the feasible behaviors

3. **Driving Behavior Realization**
   All possible car motions when executing a given behavior is represented by a GP. The adaptation of GP to a given behavior is performed using a geometrical transformation known as “least square conformal map” (LSCM)

4. **Probabilistic Collision Risk estimation**
   It is calculated for a few seconds ahead from the probability distributions over Behaviors (Behavior recognition & Behavior realization)
Motion prediction – Learn & Predict approach

- Observe & Learn “typical motions”
- Continuously “Learn & Predict”
  - Learn => GHMM & Topological maps (SON)
  - Predict => Exact inference, linear complexity

Experiments using Leeds parking data

Euron PhD Thesis Award 09
Collision Risk Assessment – Functional Architecture

Estimate the probability of the feasible driving behaviors

Probabilistic representation of a possible evolution of a car motion for a given behavior

Probabilistic Collision Risk: Calculated for a few seconds ahead from the probability distributions over Behaviors Recognition & Realization

Additional Sensors (light indicators, etc.)
Road Geometry

Probabilistic Vehicle Evolution
Behaviour Estimation
Behaviour Realization

Ego-Vehicle Trajectory
Risk Estimation

N targets

Patent INRIA & Toyota 2009
• Behaviors Modeling: *Hierarchical HMM* (learned from driving observations)

\[ P(B_t|O_{1:t}) = L_{B_t}(O_{1:t}) \sum_{B_{t-1}} P(B_{t-1})P(B_t|B_{t-1}) \]

e.g. Overtaking => Lane change, Accelerate …

• Behaviors Prediction: *Probability distribution of the feasible behaviors*
• Driving Behaviors Realization & Uncertainty:  *Gaussian Process*

![Diagram showing Gaussian Process](image)

Example: Two GPs associated to the Ego Vehicle (B) and to another Vehicle (A).

![Diagram showing road geometry](image)

Canonical GP deformed according to the road geometry (using LSCM).

• Probabilistic Collision Risk Assessment:

- Sampling of trajectories from GP: Fraction of samples in collision gives the risk of collision associated to the behavior represented by GP.

- General risk value is obtained by marginalizing over behaviors based on the probability distribution over behaviors obtained from the layered HMM [Tay 09].

\[
P(Y|X_n) = \mathcal{GP}(\mu_n, \Sigma_n) \\
\mu_n = K(X_n, X) [K(X, X) + \sigma^2 I]^{-1} Y \\
\Sigma_n = K(X_n, X_n) - K(X_n, X) [K(X, X) + \sigma^2 I]^{-1} K(X, X_n)
\]

Risk Assessment

Behavior belief table for each vehicle in the scene + Road geometry (GIS) + Ego vehicle trajectory to evaluate = Evaluation

Collision probability for ego vehicle
High-level Behavior prediction for other vehicles (Observations + HMM)

Behavior Prediction (HMM) + Observations

Risk Assessment (GP) + Road geometry (GIS) + Ego vehicle trajectory to evaluate

Behavior belief table for each vehicle in the scene

Behavior models

Prediction

Collision probability for ego vehicle

Experimental validation: Toyota Simulator + Driving device
Collision Risk Assessment – Experimental results (Real data)

Behaviors prediction on a highway (Real time)

*Cooperation Toyota & Probayes*

Equipped Toyota Lexus

Stereo camera

Ibeo Lux

IMU + GPS + Odometry

Performance summary (statistics)
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Maneuvers prediction at roads intersections
Cooperation Stanford & Renault

Scenario

- A vehicle is approaching, then crossing an intersection

Available information

- => perception, previous mapping, communication ...
- Digital map of the road network
- State of the vehicle: position, orientation, turn signal
- Associated uncertainty

Objective

- At any t, Estimate the Manoeuvre Intention of the driver of the approaching vehicle

[Lefevre & Laugier & Guzman IV’11]
Digital map & Typical paths acquisition

- **Intersection map** obtained using *Google Map*, an annotated using the *RNDF format*
- **Typical paths** are obtained with a 3D laser (velodyne), by observing real traffic

- 40 recorded trajectories have been manually annotated
- 2 datasets have been constructed with these trajectories, by automatically annotating the turn signal
  - ✓ 40 trajectories with *consistent turn signal*
  - ✓ 40 trajectories with *inconsistent turn signal*
Intersection model & Maneuvers prediction

[LeFevre & Laugier & Guzman IV’11]

- Modeling a road intersection (using RDNF format,
  ✓ Road $R_i$
  ✓ Entrance lane $L_i$
  ✓ Exit lane $M_i$ (= Maneuver)
  ✓ Exemplar path $P_i$ (one per authorized crossing maneuver)

- Predicting Maneuvers: Bayesian Networks with uncertain evidence
  ✓ Variables and decomposition

$$P(M, R, L, T, P) = P(M) \times P(R|M) \times P(L|R, M) \times P(T|L, M) \times P(P|L, M)$$

✓ Specification of the conditional probabilities
  ○ Extract relevant information from the digital map (generic)
  ○ Rule-based probabilistic algorithm
Experimental evaluation: Qualitative Results

- Consistent turn signal
- Inconsistent turn signal
Experimental evaluation: Quantitative Results

• Definitions
  ✓ $m_A, m_B =$ most probable manoeuvre and second most probable manoeuvre
  ✓ Undecidable prediction: $P(m_A) - P(m_B) \leq 0.2$
  ✓ Incorrect prediction: $P(m_A) - P(m_B) > 0.2$ and $m_A$ is incorrect
  ✓ Correct prediction: $P(m_A) - P(m_B) > 0.2$ and $m_A$ is correct

• Results on 2 datasets (40 trajectories each)

   ![Consistent turn signal](image1)
   ![Inconsistent turn signal](image2)
Conclusion

• Thanks to recent advances in the field of Robotics & ICT technologies, Smart Cars & ITS are gradually becoming a reality

Parking Assistant (e.g. Toyota Prius)

Volvo Pedestrian avoidance system (2010)

Fully Autonomous Driving (2025?)

First implemented system (Laugier & Paromtchik 97)

• Bayesian Perception, Prediction and Collision Risk Assessment are key components for improving System Robustness & Driving Safety

• Further work is still needed for:

  ✓ Addressing more complex traffic situations involving human beings
  ✓ Improving the embedded system efficiency
  ✓ Performing intensive testing & ground truth
Some related publications

- Handbook of Intelligent Vehicle, Part on “Autonomous Vehicles” (C. Laugier, Guest editor), To appear Nov. 2011


