Fusion of evidential occupancy grids for cooperative perception

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Outline

1. Motivation
   - Autonomous navigation problem
   - Objective
2. Proposed solution
   - Evidential occupancy grids
   - Generation
   - Localisation and cooperation
   - Fusion
3. Experimental results
   - Acquisition setup
   - Performance evaluation
   - Conclusions and perspectives

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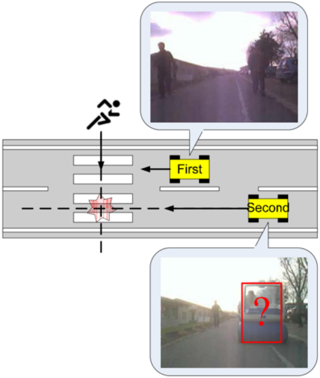
Autonomous navigation problem

- Intelligent vehicles
- Sensors to perceive the environment
- Wireless communication modules

Autonomous navigation problem

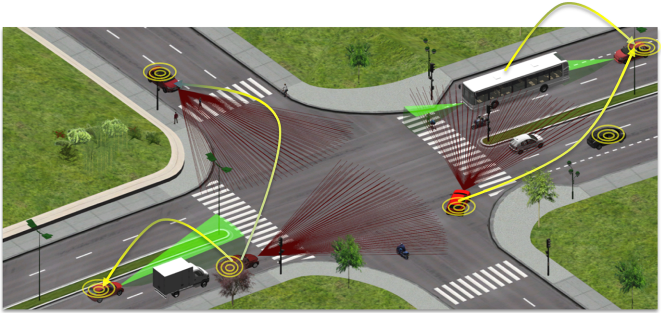
- Perception subproblem
- Partial distributed knowledge
- Restricted view



[0] Illustration from H. Li and F. Nashashibi, "A new method for occupancy grid maps merging"

Autonomous navigation problem

- SoS approach
- Cooperative perception



Objective

Design, implement and study a solution able to:

- Build for each vehicle a representation of the environment
- Update it with upcoming data from its own sensors
- Enrich it with the point of view of other vehicles

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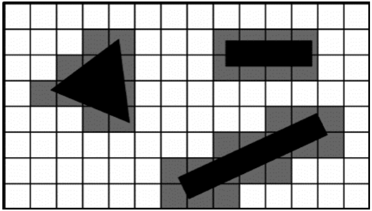
Proposed solution

1. Evidential occupancy grids as environment representation
2. Built on Lidar scans
3. Localised with GNSS (RTK), broadcasted via Wifi
4. Grids transformation and fusion

1. Evidential occupancy grids
Occupancy grids

- 2D representation
- Navigable space



1. Evidential occupancy grids

Belief functions theory - Mass function

1. Binary grids

$$O_{i,j} = true \qquad F_{i,j} = false$$

2. Probabilistic grids

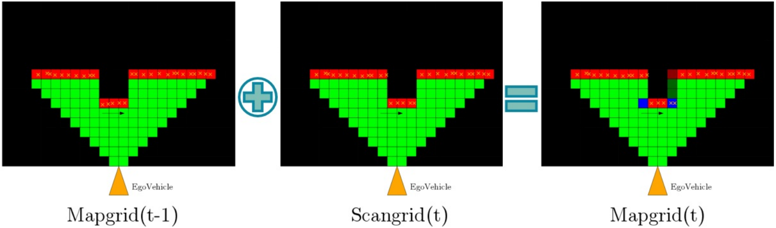
$$P(O_{i,j}|z) = 0.7 \qquad P(F_{i,j}|z) = 0.3$$

3. Evidential grids

$$m_{i,j}(\cdot|z) = \begin{bmatrix} \emptyset & O & F & \Omega \\ 0 & 0.7 & 0 & 0.3 \end{bmatrix} \qquad \Omega = \{F, O\}$$

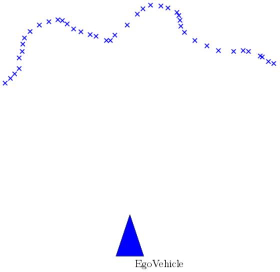
1. Evidential occupancy grids
Belief functions theory - Features

1. Ignorance representation
2. Information fusion (Conjunctive rule, Dempster's rule, ...)



2. Generation
Lidar

- Light Detection And Ranging
- Pulsed laser light to measure distances
- Widely used in autonomous navigation (Google Car, Uber, ...)



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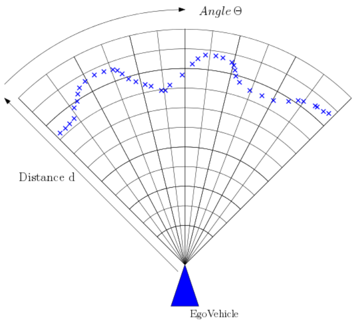

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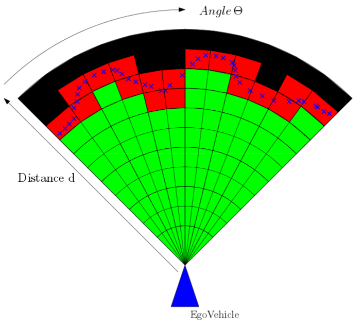

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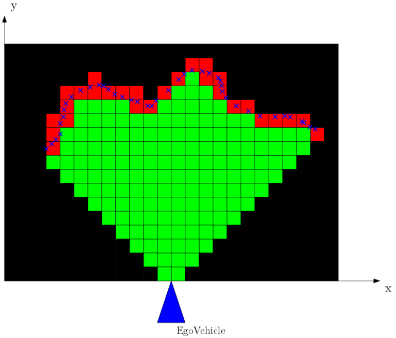


3. Localisation and cooperation

GNSS (RTK)

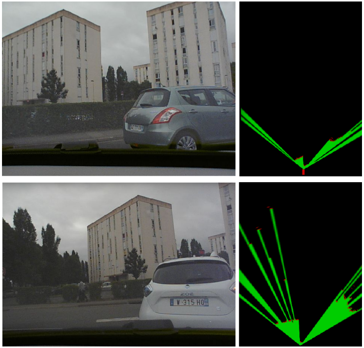
- Position estimation with centimeters accuracy
- Requires base station
- Combined with tachometer and gyroscope to estimate heading

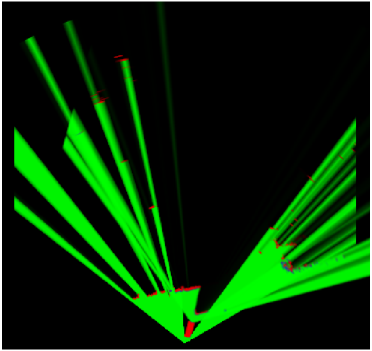
Broadcast Wifi

- IEEE 802.11 standard for vehicular communication
- Opportunistic and connectionless communication

4. Fusion

- Grid transformation according to position estimation
- Cell-by-cell information fusion with Dempster's rule





Outline

Acquisition setup

- Real data acquired on the road (over 30 minutes of sensor flow recording)
- Synchronized acquisitions on 2 vehicles in platooning
- Offline generation and fusion of grids
- Simulated (ideal) wireless communication

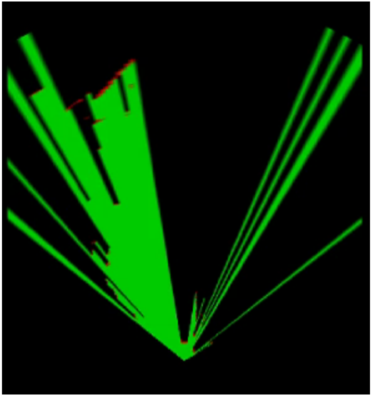
Performance evaluation

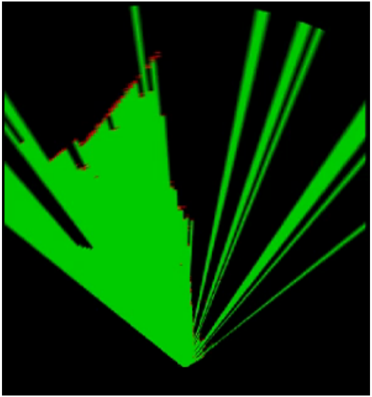
- No ground truth
- Poor position estimation leads to unaligned grids fusion
- In our case, front vehicle regularly appears in the back vehicle's field of view

ConflictError indicator

Amount of evidential conflict between GNSS estimated position and effective Lidar measurement.

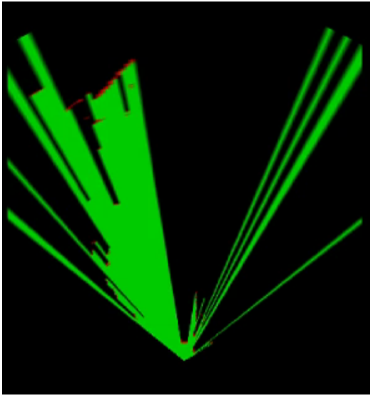
Performance evaluation





- *Back vehicle*
- *Front vehicle*

Performance evaluation



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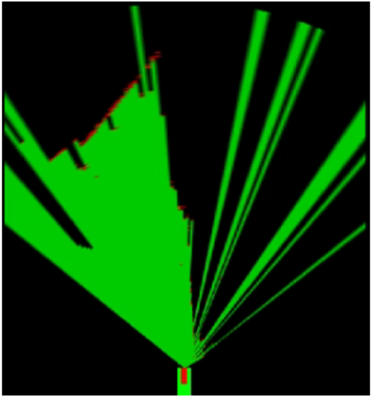
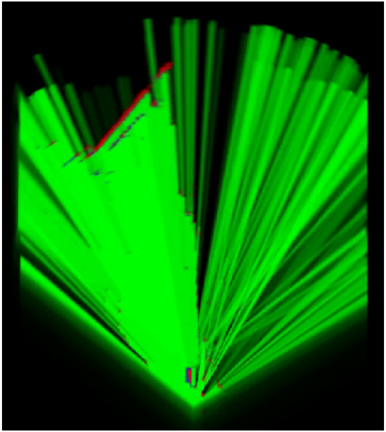


- *Front vehicle*

Performance evaluation



- The amount of conflict reported in the fusion process gives an indication of the two grids compatibility and alignment:

$$ConflictError = \sum_{cell_{i,j} \in OV} m_{i,j}(\emptyset)$$

(where OV is the set of cells belonging to the other vehicle)

Video

Conclusions and perpectives

Results

- Working prototype of cooperative perception application
- Overall SoS urban scene understanding results enhanced
- Outcome strongly depends on position estimation accurancy

Possible continuations

- Expansion of Ω to $\Omega = \{F, D, S\}$ supporting classification of dynamic (D) and static (S) cells
- Implementation of grid alignment algorithms