INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE

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Low-cost precise localization of mobile vehicles in dense urban areas

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IGN, SRIG, MATIS

October 17, 2014

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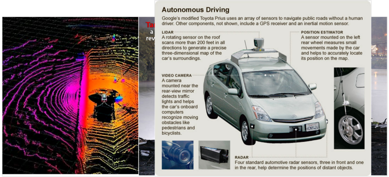
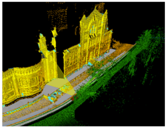
Context

Context

Precise localization in dense urban area:

- ADAS
- Autonomous navigation
- Mobile mapping systems





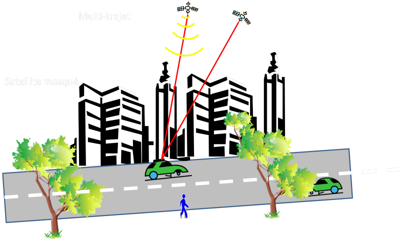
Google, USA: street view car

IGN, France: stereopolis

State of the art

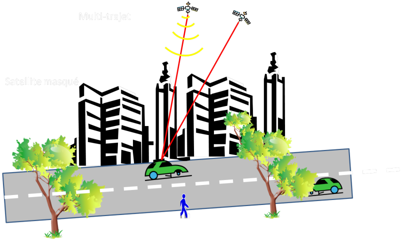
Direct localization systems

- GNSS



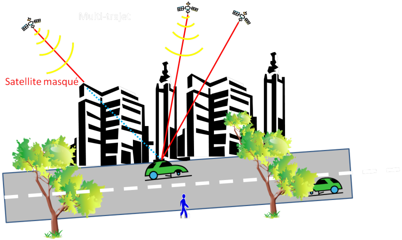
Direct localization systems

- GNSS
  - ☺Advantages
    - Absolute localization
    - No error accumulation



Direct localization systems

- GNSS
  - ☺Advantages
    - Absolut localization
    - No error accumulation
  - ☹Drawbacks
    - Masks



Direct localization systems

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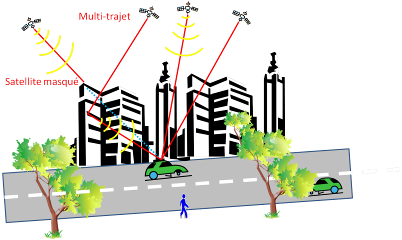
    - Masks
    - Multi-path
    - Bad geometric configurations



Direct localization systems

- GNSS
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    - Bad geometric configurations
- INS/Odometer
  - ☺Relative localization
  - ☺High precision in short term

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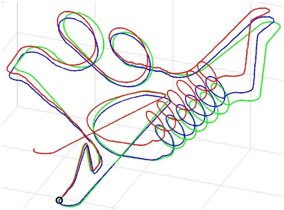
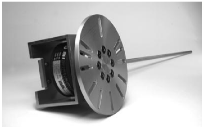


Direct localization systems



- **GNSS**
  - ☺Advantages
    - Absolut localization
    - No error accumulation
  - ☹Drawbacks
    - Masks
    - Multi-path
    - Bad geometric configurations

- **INS/Odometer**
  - ☺Relative localization
  - ☺High precision in short term
  - ☹Error accumulation in long term
- **Hybridisation : GPS + INS + Odometer**
  - High precision but expensive

Vision-based localization systems

- Vision-based methods
  - Visual odometry (D.Nistér, 04)
  - SLAM (A. Davison et al., 03)
- ☺Low-cost,
- ☹Drift

- Vision-based Using external data
  - GPS (Lhuillier et al., 12)
  - 3D Patches
  - 3D city models
- ☺Decrease drift
- ☹Long GPS masks
- ☹Precision depends on the map

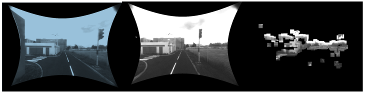


Figure: (Charmette et al., 10): Localization image, learning image, patches reconstruction

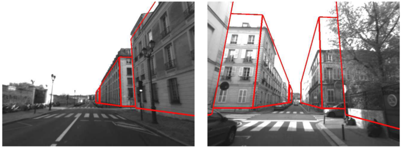


Figure: (Lothe et al., 09): Projection of 3D models after localization

Proposed method

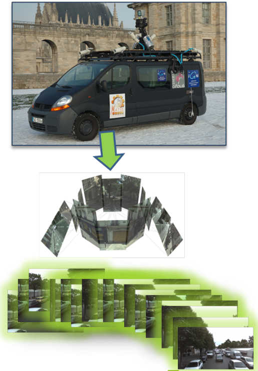
Proposed strategies

Associate the online camera data with respect to a geo-referenced database of road infrastructures

Proposed strategies

Associate the online camera data with respect to a geo-referenced database of road infrastructures

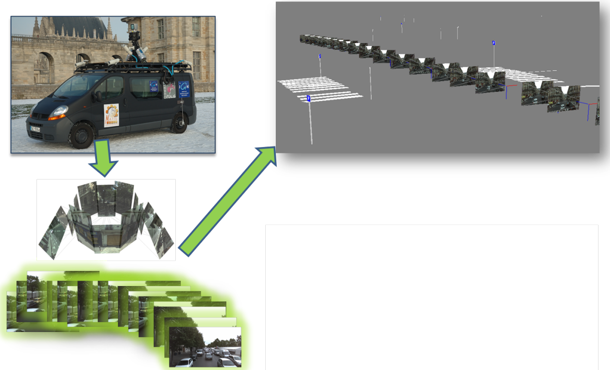
- Acquisition of reference data by a mobile mapping vehicle



Proposed strategies

Associate the online camera data with respect to a geo-referenced database of road infrastructures

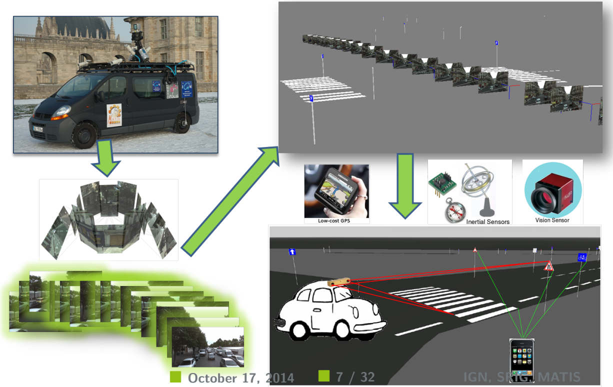
- Acquisition of reference data by a mobile mapping vehicle
- Generation of a 3D database of geo-referenced visual landmarks



Proposed strategies

Associate the online camera data with respect to a geo-referenced database of road infrastructures

- Acquisition of reference data by a mobile mapping vehicle
- Generation of a 3D database of geo-referenced visual landmarks
- Align an image or image sequence with respect to the reference database



Stereopolis

Components:

- Localization system
- Sensors
- Storage system
- Control system

Localization system

Localization system : Applanix POS-LV220

- IMU: Inertial Measurement Unit
- DMI: Distance Measurement Indicator
- GPS Antennas

DGPS performance:

	With GNSS post-processing	GNSS outage $60s$ post-processing
X,Y Position (m)	0.020	0.240
Z Position (m)	0.050	0.130
Roll and Pitch (°)	0.020	0.060
Heading (°)	0.025	0.030

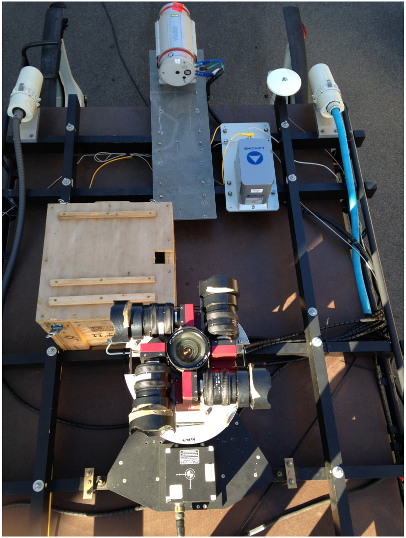
Optical sensors

Two forward-rear looking stereo pairs

- PIKE F-210C

Five wide angle cameras providing 360°

- PIKE F-421 B/C



Optical sensors

Two forward-rear looking stereo pairs

- PIKE F-210C

Five wide angle cameras providing $360°$

- PIKE F-421 B/C

Optical sensors of stereo pairs

PIKE F-210C:

- Picture size: 1920×1080 pixels
- ADC:12 bits
- Frame rates up to 31 fps
- Chip size : $14\ mm \times 7\ mm$
- Cell size : $7.4\mu m \times 7.4\mu m$

Lens:

- Focal length : $10\ mm$
- Aperture range 1.9–16
- Opening angle $70°$

Optical sensors of panoramic head

PIKE F-421 B/C:

- Picture size: 2048×2048 pixels
- ADC:14 bits
- Frame rates : 1.875 fps – 30 fps
- Chip size : $15\ mm \times 15\ mm$
- Cell size : $7\mu m \times 7\mu m$

STILAR 2.8/8 lens:

- Focal length : $8.5\ mm$
- Aperture range 2.8–11
- Opening angle $> 90^\circ$

Lidar

Context

State of the art

Proposed method

▶Strategies

Mapping

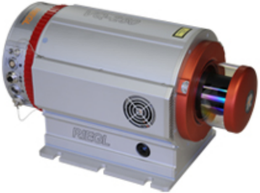
Localization

Experiments and evaluations

Conclusions and perspectives

RIEGL VQ-250

- Time of flight measurement
- High scan speed up to 100 scans/sec
- Number of targets per pulse : 5–15
- Min. range : $1.5\ m$, Max. range: $500\ m$
- Rotating mirror
- Field of view : 360°
- Angular step $\Delta\phi$: $0.018^\circ \leqslant \Delta\phi \leqslant 0.72^\circ$
- Angle measurement resolution : 0.001°
- Accuracy : $10\ mm$
- precision : $5\ mm$
- Echo signal intensity ! 16 bit
- Electrical interfaces for GPS data string and Sync Pulse (1PPS)



Lidar

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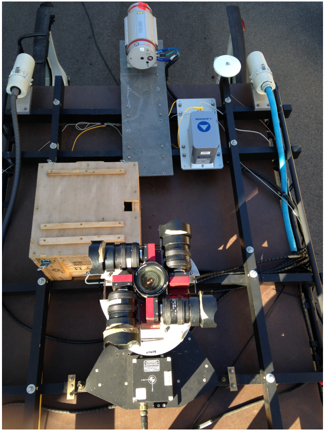
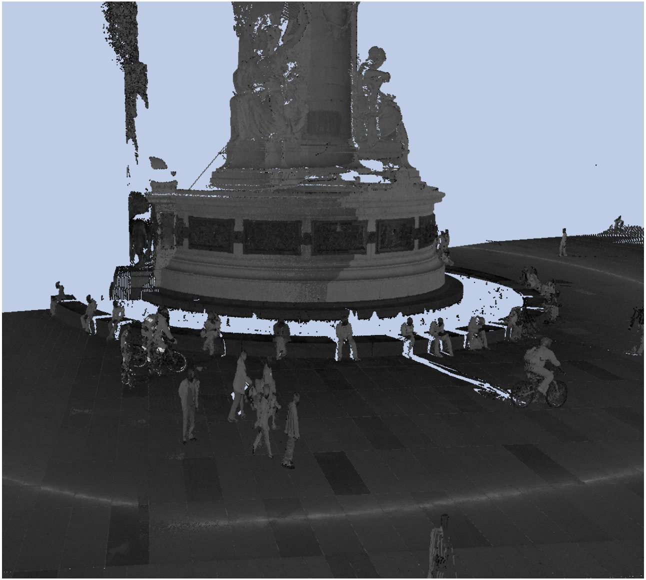


Georeferenced data



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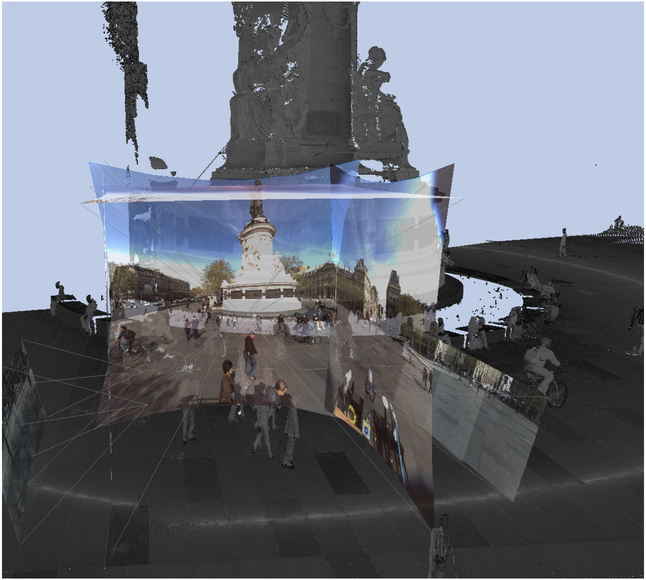


Generation of a 3D road infrastructure database

Road infrastructures

Visual landmarks (semantic features):

- road signs, road surface markings, traffic lights
- Curbs, building facades, etc.

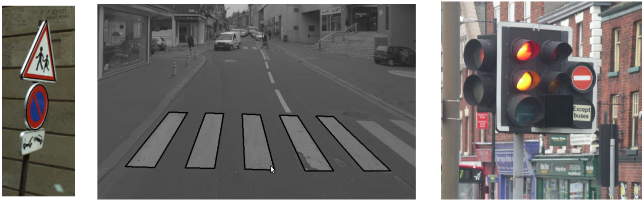


Figure: Semantic landmarks

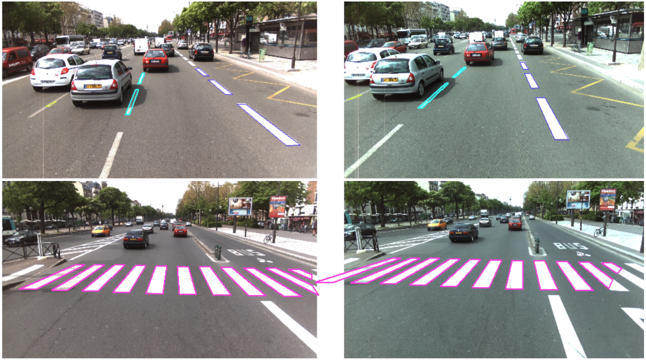
Advantages

- Stable to time and viewpoint changes
- Precision and robustness of landmarks (with estimated uncertainty)
- Less volume for data storage and matching

Generation of road infrastructure database

Map of 3D road markings (Soheilian et al. 2010)

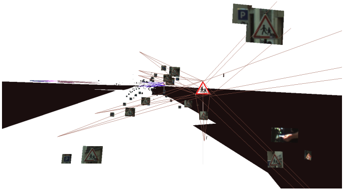
- Input: a pair of images
- Output: 3D model of markings in sub-decimeter accuracy: parallelogram

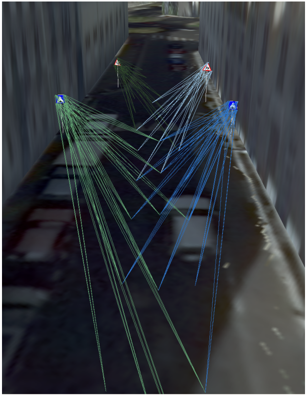


Generation of infrastructure database

Map of road signs (Soheilian et al. 2013)

- Input: a set of geo-referenced color images
- Output: 3D model of road signs in sub-decimeter accuracy: 3D rectangle, triangle, or circle



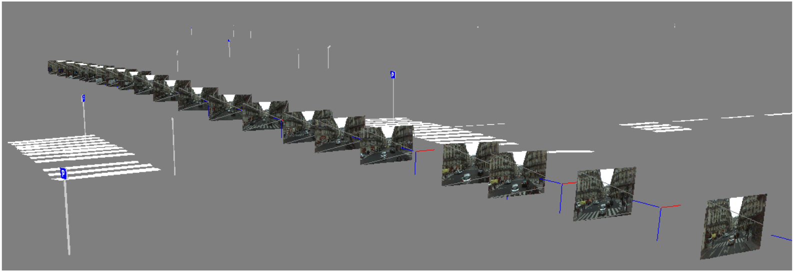


Generation of infrastructure database

A geo-referenced road infrastructure database including:

- Map of 3D road markings
- Map of 3D road signs

With simple geometric shape: road sign (polygon, triangle, or circle), road marking strip (parallelogram).



Vehicle localization with road infrastructure database

Localization aided by visual landmarks

Sensors: (GPS + INS + cameras) low prices

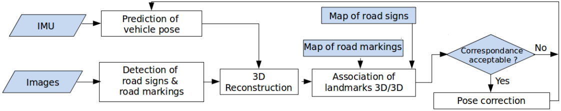
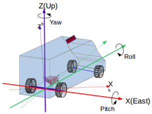


Figure: Procedure of EKF based localization



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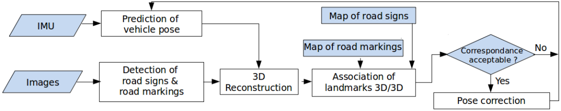
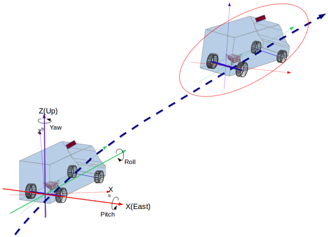


Figure: Procedure of EKF based localization

Steps:

- Pose prediction with accelerations



Localization aided by visual landmarks

Sensors: (GPS + INS + cameras) low prices

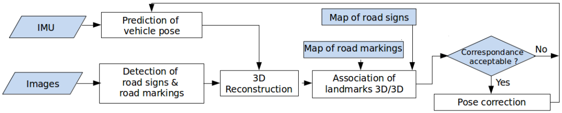
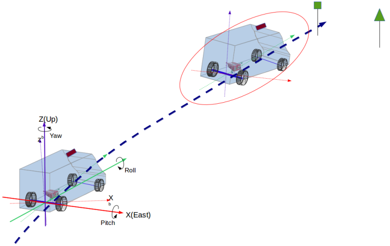


Figure: Procedure of EKF based localization

Steps:

- Pose prediction with accelerations
- Detection and reconstruction: cameras



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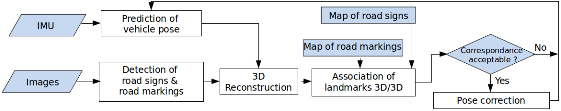
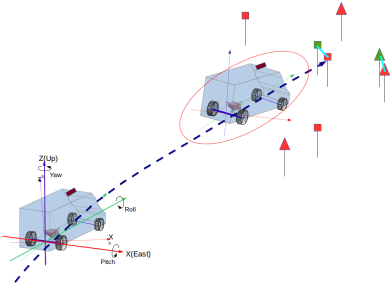


Figure: Procedure of EKF based localization

Steps:

- Pose prediction with accelerations
- Detection and reconstruction: cameras
- Association of visual landmarks



Localization aided by visual landmarks

Sensors: (GPS + INS + cameras) low prices

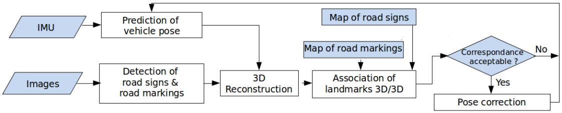
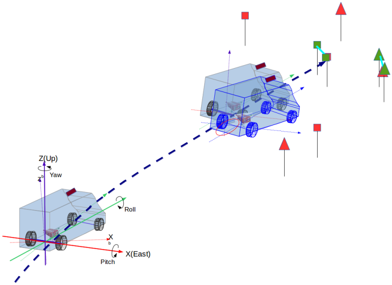


Figure: Procedure of EKF based localization

Steps:

- Pose prediction with accelerations
- Detection and reconstruction: cameras
- Association of visual landmarks
- Correction



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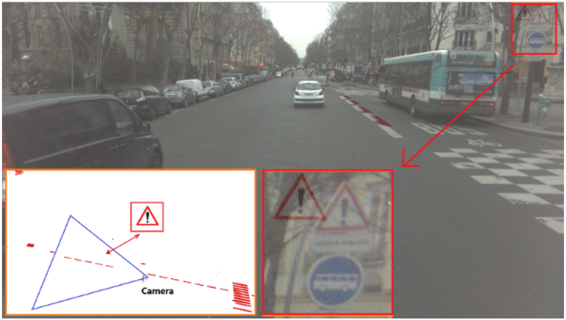


Figure: Projection of 3D road sign and road marking landmarks on an image frame with raw camera pose

let R be the attitude of current vehicle state, $F_j(x, y, z)$ be the center of a landmark in the database, the expected 3D position EM_j of the landmark F_j in current vehicle frame is as:

$$EM_j = R^{-1}(F_j - X_k) \quad (1)$$

Matching criteria between two 3D landmarks

Between 2 road signs:

1. Type;
2. Direction of road sign plane;
3. Mahalanobis distance between two sign centers;
4. Unique constraint.

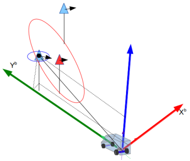


Figure: Between 2 road signs

Between 2 road marking strips:

1. Type;
2. Direction of road marking plane;
3. Mahalanobis distance between the center of marking strips ;
4. Unique constraint.

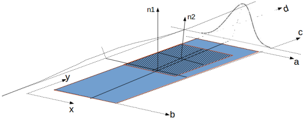
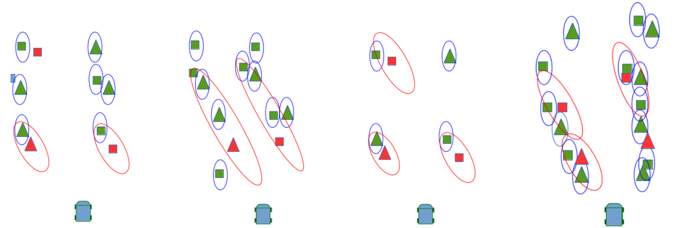


Figure: Between 2 strips of markings

Matching ambiguities



(a) Small INS error (b) Big INS error (c) Small density of landmarks (d) Large density of landmarks

Figure: Association of landmarks in different conditions

Compatibility between different landmarks by using:

- **Nearest neighbor search**
- **Multi-hypothesis filter**

Experiments and evaluations

Experimental data

- **Reference: Paris VI, 12km, 2012; 120 road signs**

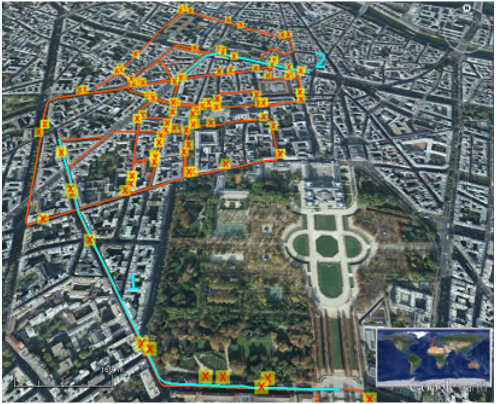


Figure: Database of visual landmarks

Reference images	Vehicle trajectory	Number of road signs	Number of markin
2015×12 *cameras*	12km	120 (351k)	2116 (890k

Experimental data

- Reference: Paris VI, 12km, 2012; 120 road signs
- **Two test segments: 1013m and 533m**

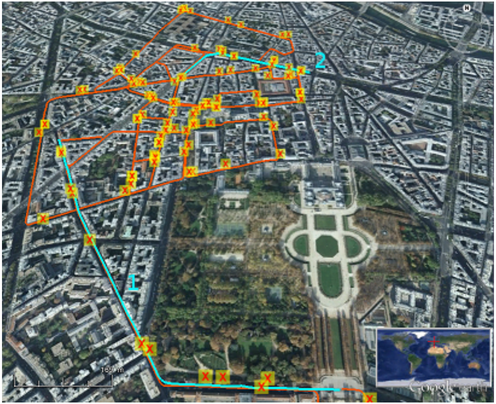


Figure: Database of visual landmarks

Pose ground truth of the test sequence were provided by GPS/INS/odometer post-processing software

Evaluation

- True positive (TP): landmarks were detected in images and associated with the corresponding database landmarks;
- False positive (FP): landmarks were detected in images, but associated with wrong database landmarks;
- True negative (TN): there was no corresponding landmark of a detection due to false detection or the incompleteness of the database;
- False negative (FN): landmarks were detected in images but not associated with the corresponding landmarks in database.

Experiment 1: Results with road signs

(a) before

→

(b) after

Table: Statistic data of position correction with road landmarks

Landmarks	Signs
Locations with detections	21
TP (Correct association)	10
FP (Wrong association)	0
TN (No correspondence)	10
FN (Not associated with correspondence)	1

Experiment: Results with road signs

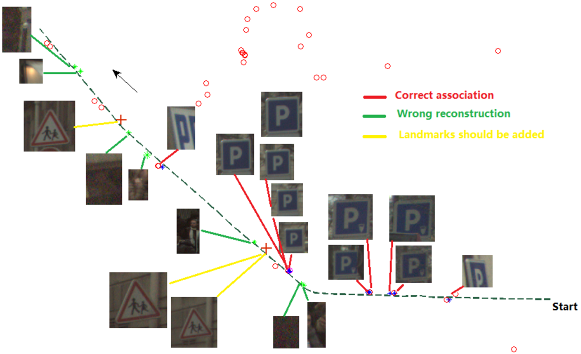
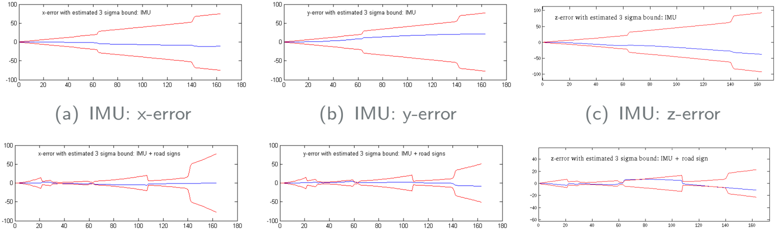


Figure: Segment 1: landmarks association results (Red line: correct association; green line: wrong detection; yellow line: landmarks to be added into the database; red circles: reference road signs)

Experiment: Results with road signs



(a) IMU: x-error (b) IMU: y-error (c) IMU: z-error

(d) IMU+road sign: x-error (e) IMU+road sign: y-error (f) IMU+road sign: z-error

Figure: Vehicle position error before (first row) and after (second row) incorporating road sign based correction. Blue curves: vehicle position error with respect to the ground truth; red curves: 3-sigma (3 times the standard deviation of the estimated position error)

Experiment: Results with road signs/road markings

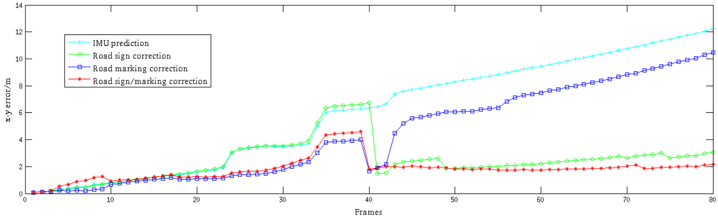
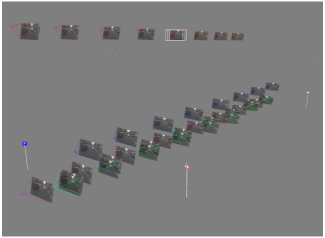


Figure: Segment 2: Vehicle position error with IMU, IMU+road sign, IMU+road marking, IMU+road sign+road marking

Experiment: Results with road signs/road markings



(a) From GPS /INS /Odometer post-processing software

(b) After incorporating the road infrastructure objects

Conclusions and perspectives

Conclusions

Conclusion:

- ☺ Alignment method of images by using a database of geo-referenced visual landmarks
- ☺ Reducing the error accumulation of INS by periodic pose correction with visual landmarks
- ☺ Localization INS : $E_p = 185m$ and $E_{alti} = 280m$
- ☺ Localization INS + landmarks : $E_p = 4.5$ and $E_{alti} = 6.7m$
- ☺ Taken into account uncertainty of all the observations (the acceleration measures from INS and the 3D visual landmarks)

Conclusions

Conclusion:

- ☺ Alignment method of images by using a database of geo-referenced visual landmarks
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- ☺ Localization INS : $E_p = 185m$ and $E_{alti} = 280m$
- ☺ Localization INS + landmarks : $E_p = 4.5$ and $E_{alti} = 6.7m$
- ☺ Taken into account uncertainty of all the observations (the acceleration measures from INS and the 3D visual landmarks)

- ☹ Searching area for landmarks matching increases with the error accumulation of INS
- ☹ Ambiguity of matching
- ☹ Risk of getting lost

Perspectives

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- Replace the inertial sensors by visual odometry or SFM and feed the semantic landmarks into bundle adjustment procedure (X. Qu 13)