Vision- and map-based non-line-of-sight satellites hybridized processing

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Introduction

Framework:

- European project: H2020 Fundamental Elements call by GSA (now EUSPA EUropean SPace Agency)

The project eMAPs is funded by the European Global Navigation Satellite Systems Agency GSA/GRANT/08/2017

European Global Navigation Satellite Systems Agency

- eMAPs project: 3DAerospace, ENAC, Ifsttar (now Université Gustave Eiffel), Sanyo

eMAPs

3D AEROSPACE ENAC IFSTTAR SYNYO

Introduction

Context:

- Satellite positioning with high accuracy and high integrity
- Urban positioning
- Automotive-range GNSS receivers

Applications:

- On-board a vehicle: a prototype of receiver has been designed during the project
- eHERMES prototype:

Dual scientific approach: vision- and map-based

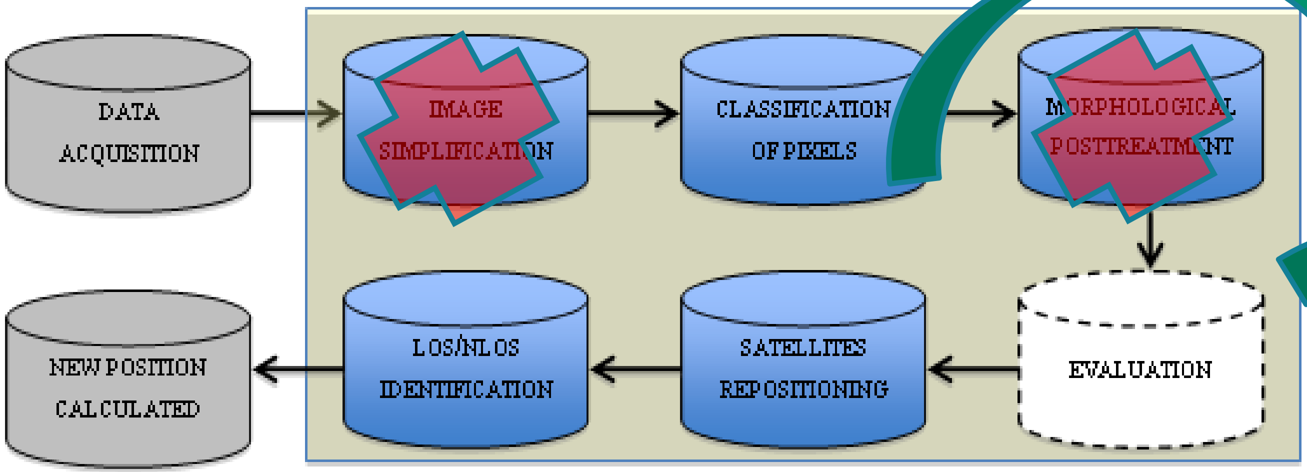
Vision-based processing:

- Fisheye camera pointing to the sky
- Image processing: an algorithm should separate sky from obstacles
- Projection of satellites into the image (assuming no tilt): => LOS/NLOS

Map-based processing:

- Local city-model: a 3D-map is available from IGN BD TOPO ® in France
- Apply ray-tracing from a position estimate: determine wether or not buildings make obstacles to tracked satellites => LOS/NLOS alternative method

Vision development strategy & its preliminary design implementation

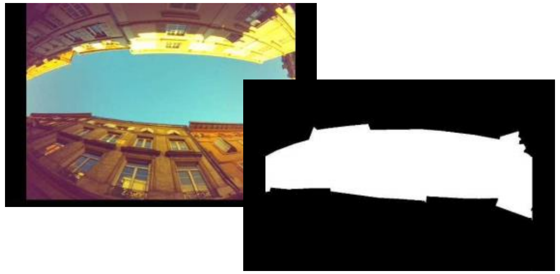


state-of-the-art ?

Target: low processing time

eMAPs full dataset
(43 683 images)

Reference sky/not-sky classification



eMAPs reduced dataset
(175 images with ground truth)

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Summary of litterature review about LOS/NLOS detection using vision

- Current state-of-the-art approaches use **convolutional neural networks**. They offer in general better results compared to more classical strategies but **require a powerful training process, dedicated hardware and a huge computational time**.

- Other works, most of which are older, offer very interesting performances. They focus on more classical **clustering techniques, applied on infrared**, **multispectral, or visible images**.

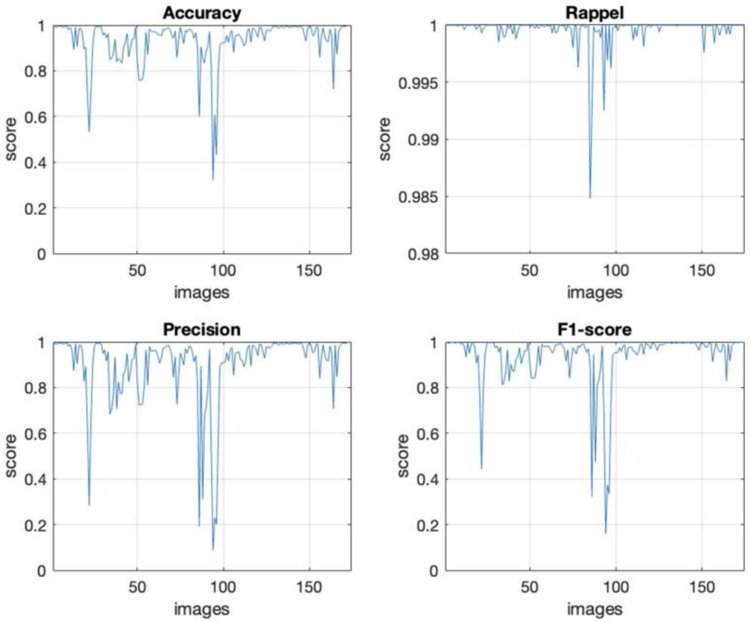
- Most methods used in the visible domain are mainly based on **edge detection** (Sobel, Canny…). **These methods are not adapted to the high complexity of our urban environment.**

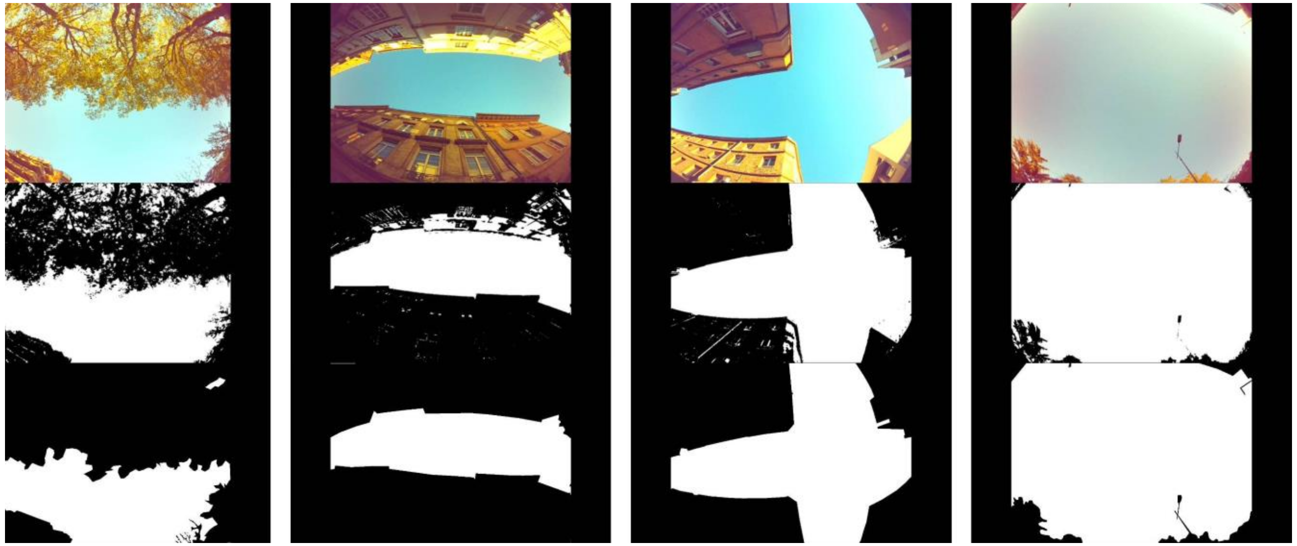
- Some papers also **combine more in-depth methods used in pre-processing for clustering** such as color space changes or segmentation methods based on graph analysis, on superpixels or combining various complementary characteristics such as texture, luminosity, points of interest... **They are to be avoided due to the low speed/performance gain.**

- **Automatic and non-parametric image thresholding** (Otsu), **supervised** (SVM, k-NN, Bayes, Neural Networks...) **or unsupervised clustering** (Fisher, K-means, Fuzzy C-means...) **seems to be interesting**.

The retained algorithm : Otsu

- **Otsu algorithm is a non-parametric and unsupervised method** based on an **automatic threshold selection** currently used in image segmentation. It allows to binarize an image by analysing its histogram and calculating an optimal threshold. This threshold value used to classify the pixels of the image into one of the two possible classes (sky and non-sky in our works) is the one that maximizes the interclass variance.

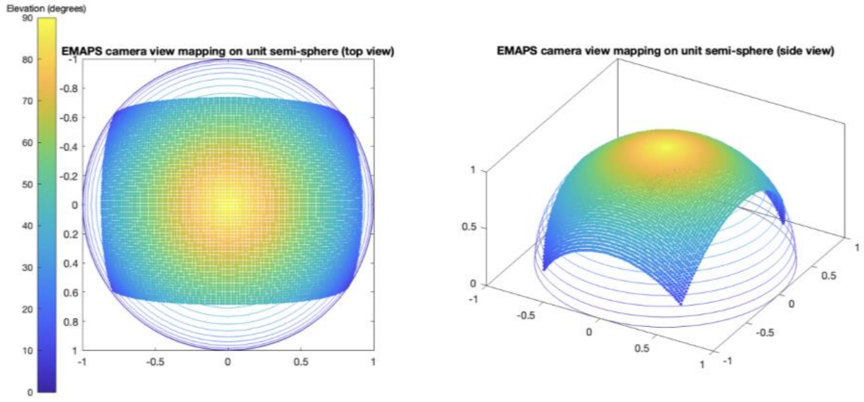


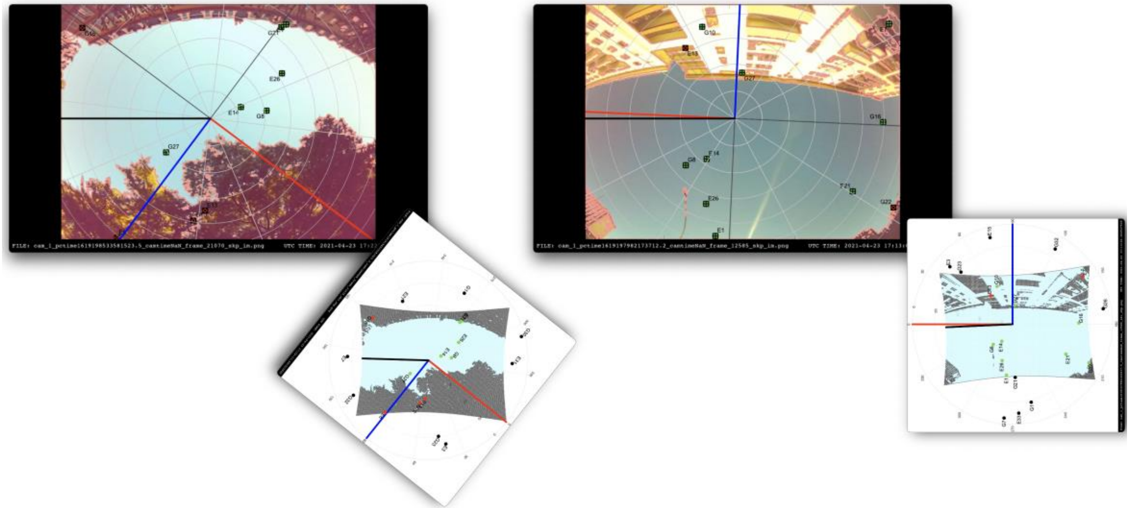


Accuracy = 93.16 %, Recall = 99.96%, Precision = 89.95%, **f1-score = 93.66%,**
Processing time = 27ms/frame.
Classification errors (3 picks on f1-score) are all due to vegetation in images => future works

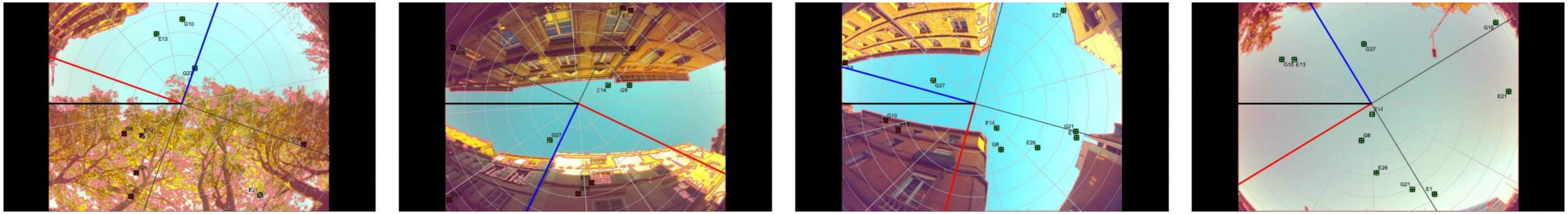
LOS/NLOS detection using vision

- Calibration of the fisheye camera for satellites repositioning. The field of view of the camera actually embedded in the first prototype is reduced => some satellite will be indeterminate



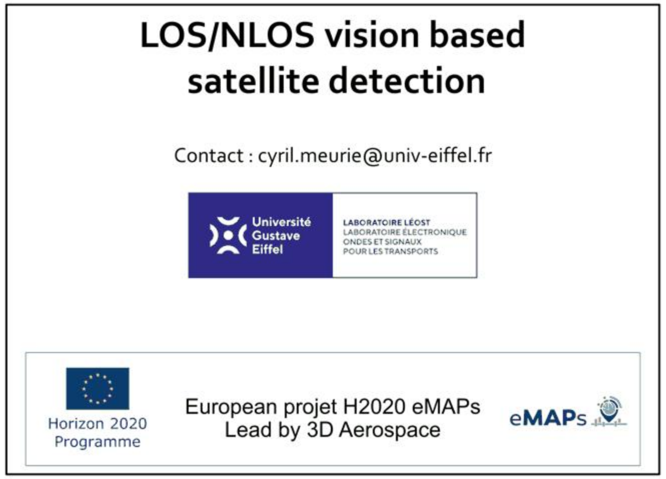


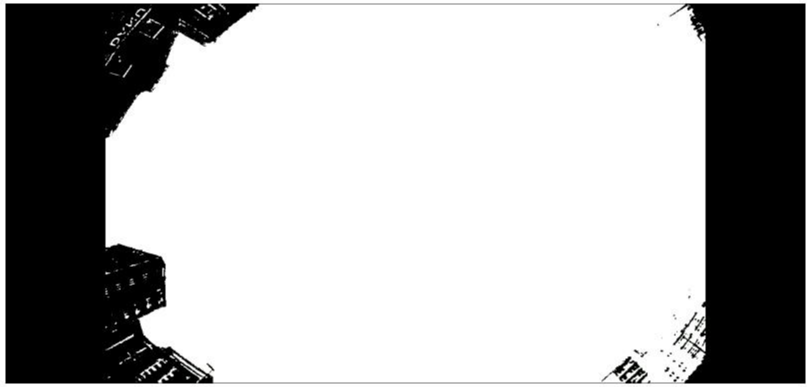
- sky/not-sky regions in the eMAPs fisheye images => LOS/NLOS detection (green/red square)



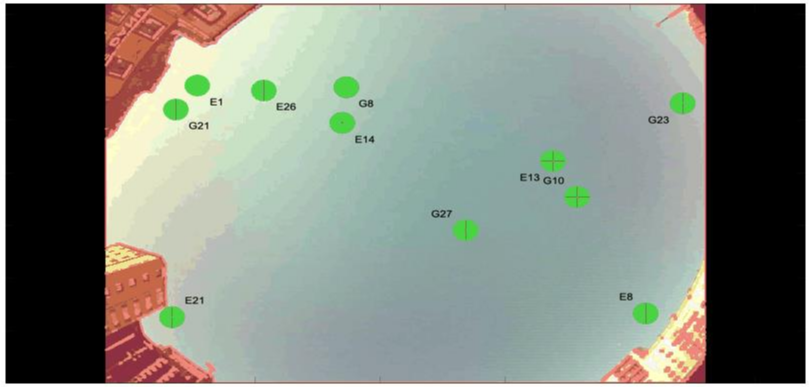
LOS/NLOS detection using vision (movie)

Vehicle position in Toulouse area





Sky/non-sky classification result



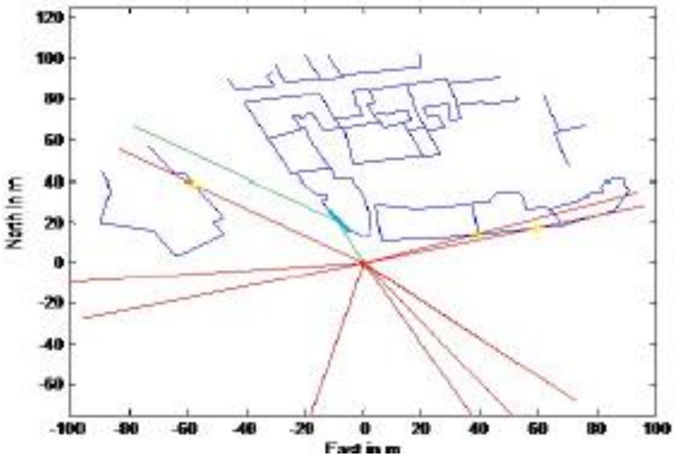
Satellite repositioning and LOS/NLOS identification

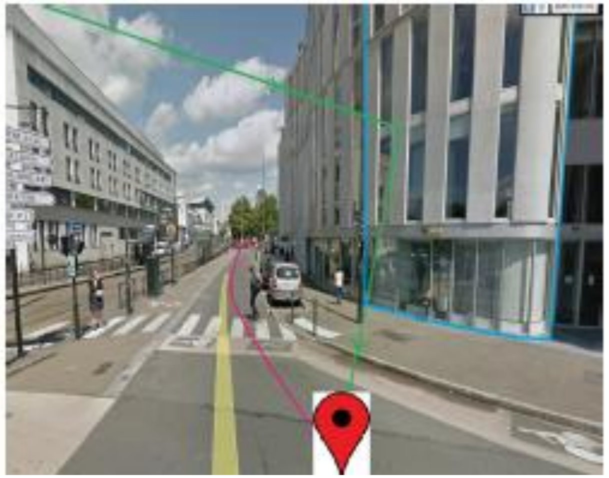
Summary of litterature review about LOS/NLOS detection using maps

- The basic idea is **to project the current rover position estimate into a 3D map model** and determine, from this point of view, whether or not satellites are LOS or NLOS.

- Fundamental works: **Bradbury et al. (2007)** Code Multipath Modelling in the Urban Environment Using Large Virtual Reality City Models: Determining the Local Environment. The Journal of Navigation and **Suh and Shibasaki (2007)** Evaluation of Satellite-Based Navigation Services in Complex Urban Environments Using a Three-Dimensional GIS. IEEE Transactions on Communications.

- Most methods progressed in the 2010's at UCL, Univ. of Tokyo, Chemnitz, ISAE… and IFSTTAR introducing **range correction** (in Urban Trenches and later in Urban Multipath model: **Ni Zhu et al. (2018)** GNSS Integrity Enhancement for Urban Transport Applications by Error Characterization and FDE, URSI-Revue d'Electricité et d'Electronique, Geolocation and Navigation in Space and Time.

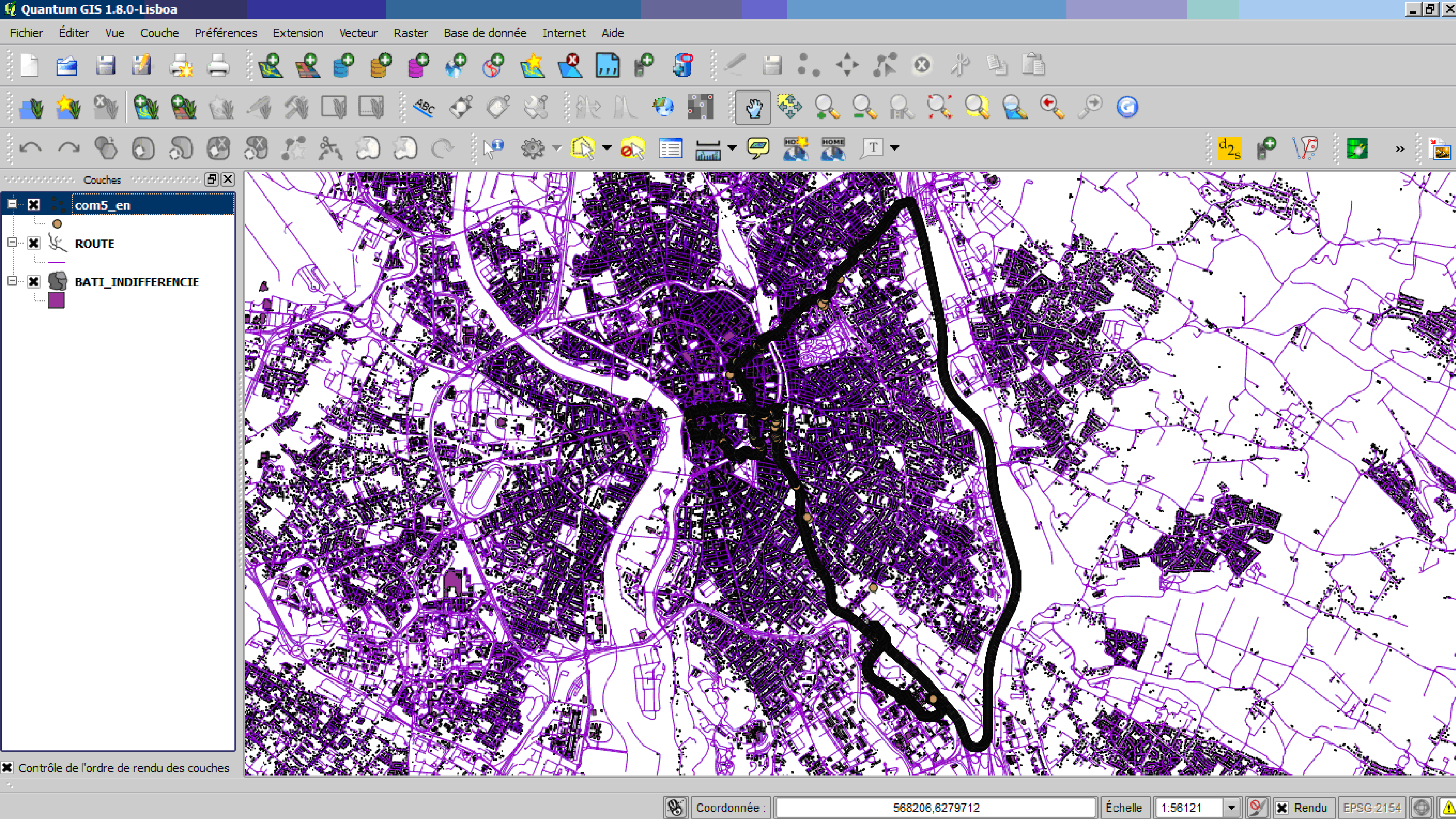




Experimental setup

- 1 hour loop in **Toulouse (project eMAPs)** on 23 April 2021 : 62 minutes, 56 in city + 6 on highway

- **Ublox F9P** multi-constellation automotive receiver (we focus on GPS), 5 Hz,
- Novatel SPAN GNSS inertial navigation system, for ground truth purpose.


Quantum GIS 1.8.0-Lisboa
Fichier
Éditer
Vue
Couche
Préférences
Extension
Vecteur
Raster
Base de donnée
Internet
Aide
Couches
com5_en
ROUTE
BATI_INDIFFERENCIE
Contrôle de l'ordre de rendu des couches
Coordonnée :
568206,6279712
Échelle
1:56121
Rendu
EPSG:2154

Navigation solver and results

- Navigation solver **Weighted Least Squares** with ranging noise similar as **RTKlib**:

$$\sigma_{GPS}^2 = 0.3^2 + 0.3^2/sin(el) + 2.4^2 + 0.3^2 + 0.3^2 + 0.5^2$$

- Elevation dependent model: **(0,3+0,3/sin(el)) m**
- **2,4m** orbital error
- Receiver noise: **0,3m**
- Atmospheric model residual error: **iono 0,3m and tropo 0,5m**

Median HPE	Highway 1855 ep	City centre 16791 ep
WLS no el mask (no ep w/o solution)	1.21m	2.69m
WLS el>15° (13 ep w/o solution)	1.79m	2.43m

Comparison of LOS/NLOS classifications

- LOS/NLOS classifications by:

- **direct (vision)** and
- **indirect (map)** methods.

- In deep urban centre, 1501 epochs with GPS measurements (5 minutes @ 5 Hz) totalizing 11821 measurements, among which the elevation and azimuth of 7270 satellites have their projection in the fisheye field.

	LOS by vision	NLOS by vision
LOS by map model	5953 svs: 81.9%	401 svs: 5.5%
NLOS by map model	502 svs: 6.9%	414 svs: 5.7%

Navigation results

- Depending on LOS/NLOS classification, the **WLS** ranging noise is **multiplied by 10** (in variance)
- The map-aided method enable **ranging correction**: **additional path travelled estimated (in m)**

Median HPE	Highway 1855 ep	City centre 16791 ep	City centre 16791 ep map-aided
WLS no el mask (no ep w/o solution)	1.21m	2.69m	2.33m
WLS el>15° (13 ep w/o solution)	1.79m	2.43m	2.40m

Navigation results (in deep urban centre)

- Navigation solver **using map correction is the most efficient** due to:
  - weighting strategy
  - AND ranging correction

Median HPE	Deep city centre 1501 epochs	Deep city centre 1501 epochs map-aided	Deep city centre 1501 epochs vision-aided
WLS no el mask	9.78m	8.85m	8.53m
WLS el>15°	8.36m	4.65m	7.02m

- Integrity improved (cf. the paper): **since W is divided by 10 in WLS… but HPL increased!**

  (we look for constant HPL in median, whilst better bounding of HPE… => future work)

- **Application to other constellations**

Acknowledgement

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