Machine Learning Based NLOS Detection

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GNSS*: Global Navigation Satellite Systems
NLOS*: Non-line-of-sight

GNSS in urban canyons

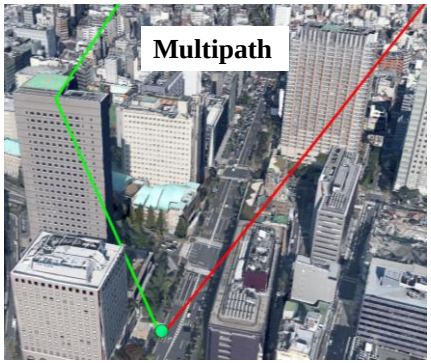
GNSS applications:

- Autonomous driving
- Unmanned aerial vehicle
- …

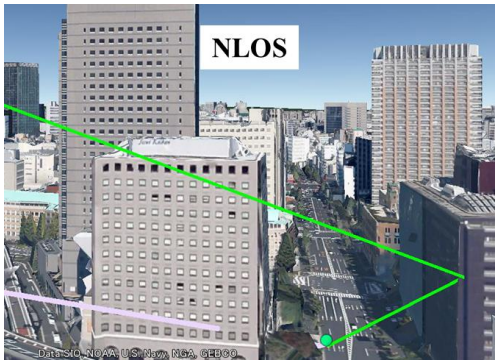
Courtesy: Google

Problem of GNSS solution in urban canyon:

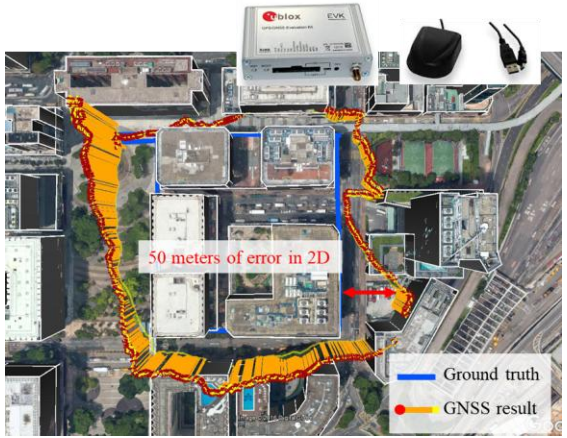
- Low availability (limited satellite numbers)
- Low accuracy (due to multipath and NLOS)



Hsu, 2016



Hsu, 2016

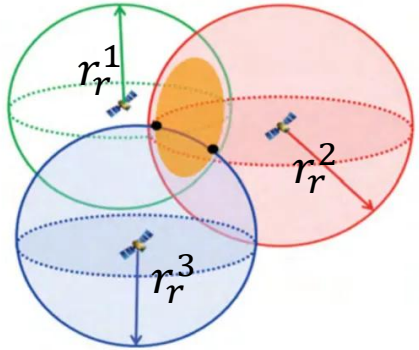


GNSS solution in Urban using u-blox M8T GNSS Receiver

[1] Hsu Li-Ta et al. "3D building model-based pedestrian positioning method using GPS/GLONASS/QZSS and its reliability calculation." *GPS solutions*, 2016

Background

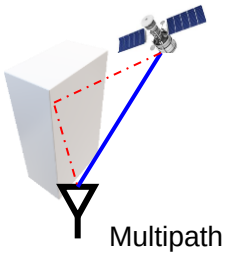
Open area

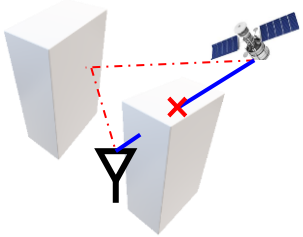


RTK Mean Error:
0.11m

Urban area

NLOS*: non-line-of-sight

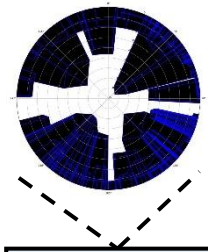

Multipath

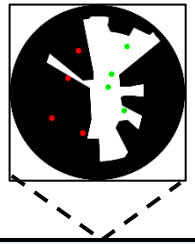

NLOS

Noisy and biased GNSS measurements

RTK Mean Error:
10m

Grafarend, Erik W., and Jeffrey Shan. "GPS solutions: closed forms, critical and special configurations of P4P." *GPS solutions* 5 (2002): 29-41.





Sky Mask Generation

Image

LOS/NLOS Identification

Model Training

Model

NLOS Detection

Ground Truth

3D building model

Satellite Information

Single Point Positioning

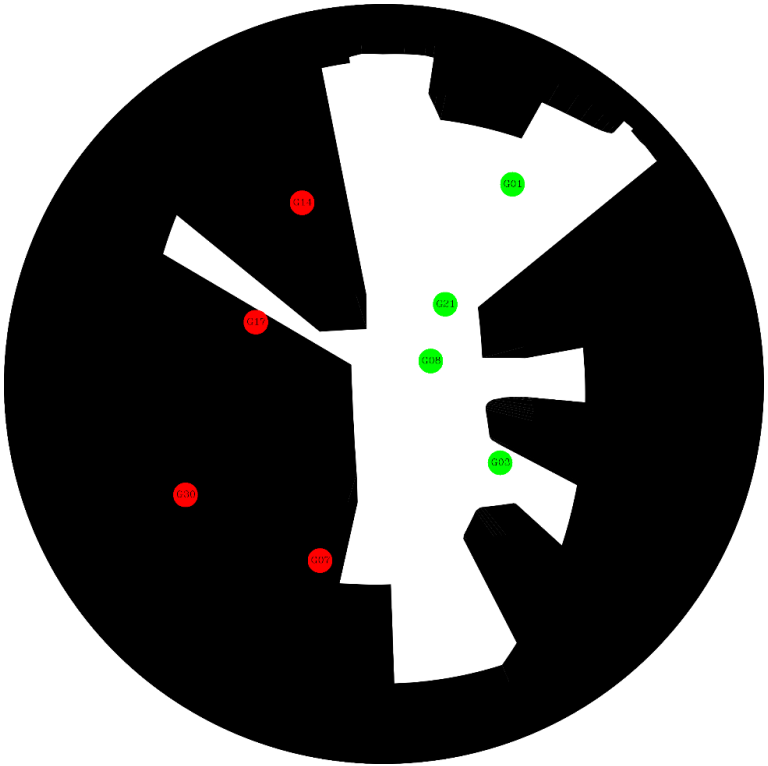
GNSS data

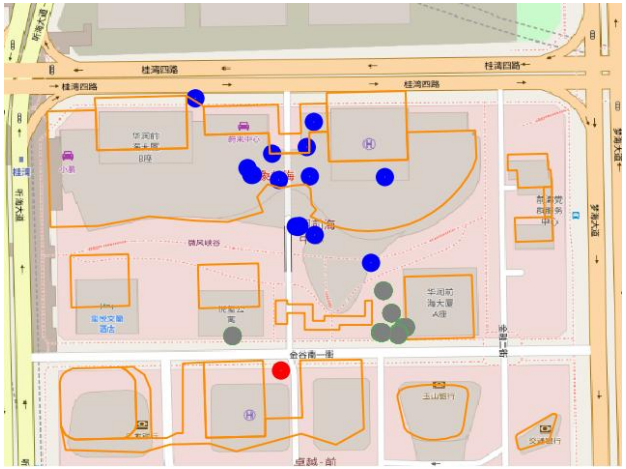
GNSS data

Down Weighting

Improved Positioning

Dataset Example 0411/OPPO/PFEM10/地点3





- SPP Error: 140.16m, 15 results available
- OPPO Error: 79.75m, 135 results available
- OPPO Fix Error: 79.75m, 135 results available

ML Aided NLOS Detection

Features Selection

- SNR

SNR (signal-to-noise ratio) measures the strength of the received satellite signal relative to background noise. Higher SNR indicates a stronger, clearer signal.

ML Aided NLOS Detection

Features Selection

- SNR
- Constellation

Different constellations may have different property. Newer constellations (e.g., Beidou) may use advanced modulation techniques that are more resistant to multipath/NLOS.

ML Aided NLOS Detection

Features Selection

- SNR
- Constellation
- Elevation Angle

Low-elevation satellites (e.g., <15°) are more prone to blockage by buildings, terrain, or vegetation. High-elevation satellites are less likely to be obstructed but can still experience NLOS in dense urban canyons.

ML Aided NLOS Detection

Features Selection

- SNR
- Constellation
- Elevation Angle
- Azimuth Angle

Urban environments often have directional obstructions (e.g., buildings along streets). Satellites aligned with open directions are more likely LOS.

ML Aided NLOS Detection

Features Selection

- SNR
- Constellation
- Elevation Angle
- Azimuth Angle
- Residual

The difference between the measured pseudorange and the pseudorange predicted by the receiver's estimated position and clock bias. Large residuals indicate measurement errors. NLOS signals often have larger residuals due to longer reflected paths or multipath interference.

$$residual = p - P(\mathbf{x}_i)$$

$$P(\mathbf{x}_i) = \sqrt{\left(x^s - x_{r_i}\right)^2 + \left(y^s - y_{r_i}\right)^2 + \left(z^s - z_{r_i}\right)^2} + c\Delta t$$

ML Aided NLOS Detection

Features Selection

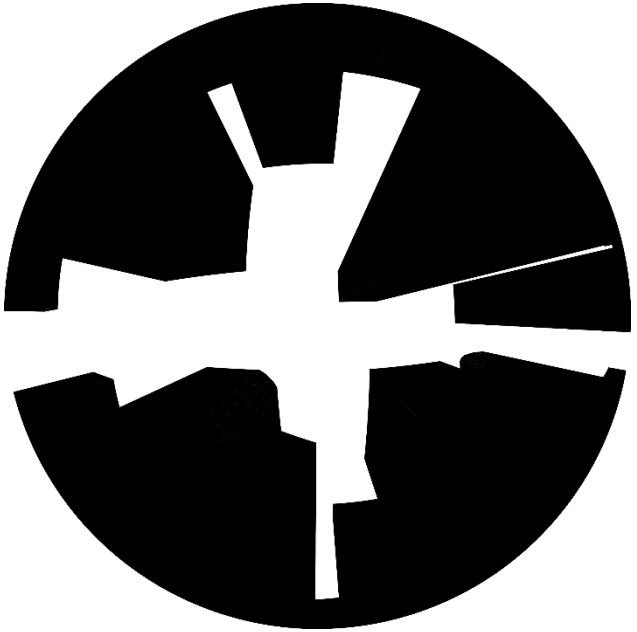
- SNR
- Constellation
- Elevation Angle
- Azimuth Angle
- Residual
- RMS Residual

The root mean square (RMS) of residuals for all satellites in a single measurement epoch (instantaneous time window). High epoch RMS indicates poor consistency across measurements, often caused by multiple NLOS/multipath signals.

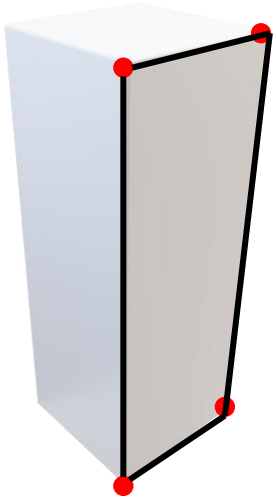
$$RMS = \sqrt{\frac{\sum_{i=1}^{n} residual_i^2}{n}}$$

ML Aided NLOS Detection

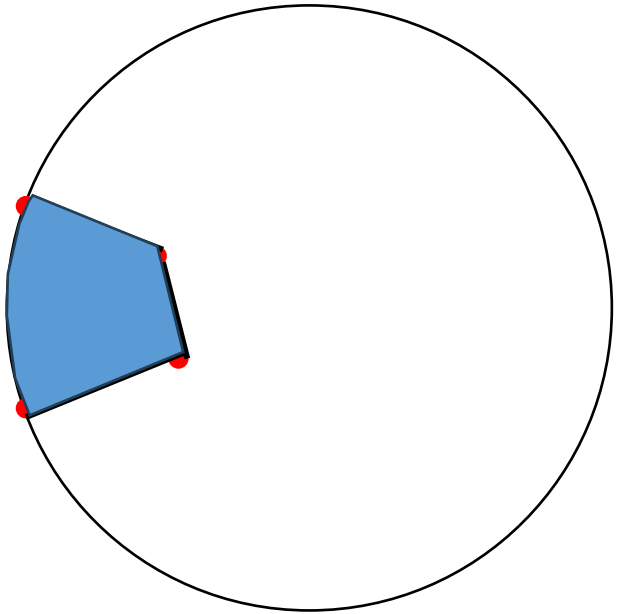
Label Generated by Ground Truth and Skymask



Skymask Generation



GT



Code Example

Code Example

Best parameters: {'bootstrap': True, 'max_depth': 10, 'min_samples_leaf': 1, 'min_samples_split': 10, 'n_estimators': 50}

	precision	recall	f1-score	support
0	0.60	0.36	0.45	14499
1	0.86	0.94	0.90	59259
accuracy			0.83	73758
macro avg	0.73	0.65	0.67	73758
weighted avg	0.81	0.83	0.81	73758

Classification Report:

	precision	recall	f1-score	support
0	0.80	0.56	0.66	56721
1	0.88	0.96	0.92	200932
accuracy			0.87	257653
macro avg	0.84	0.76	0.79	257653
weighted avg	0.87	0.87	0.86	257653