Real-time GNSS NLOS Detection and Correction Aided by Sky-Pointing Camera and 3D LiDAR

Session A6: Challenging Navigation Problems 2

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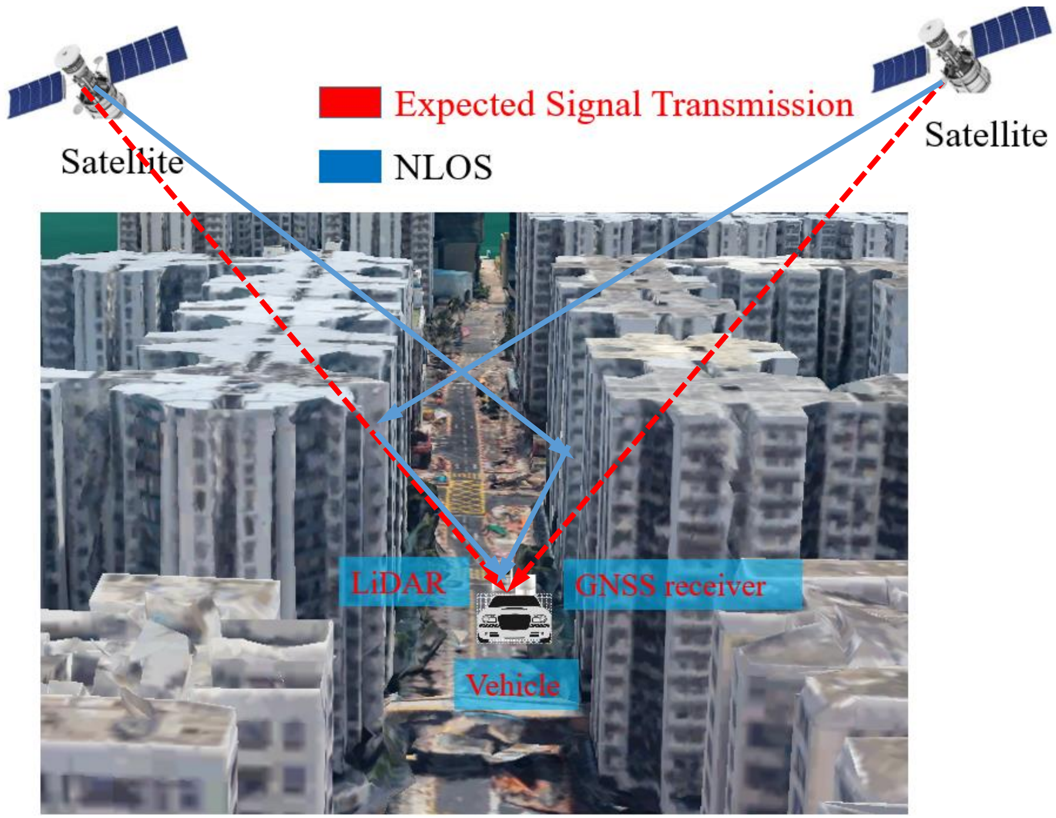
Outline

- Background
- Overview of the proposed method
- NLOS Detection Using Monocular Camera
  - Sky View Segmentation
  - Satellite Projection and LOS/NLOS Classification
- Improved GNSS Positioning With NLOS Correction
  - NLOS Correction Based on Real-time Point Clouds
  - GNSS Positioning Based on corrected Pseudorange Measurements
- Experiment Setup
- Conclusions

Background

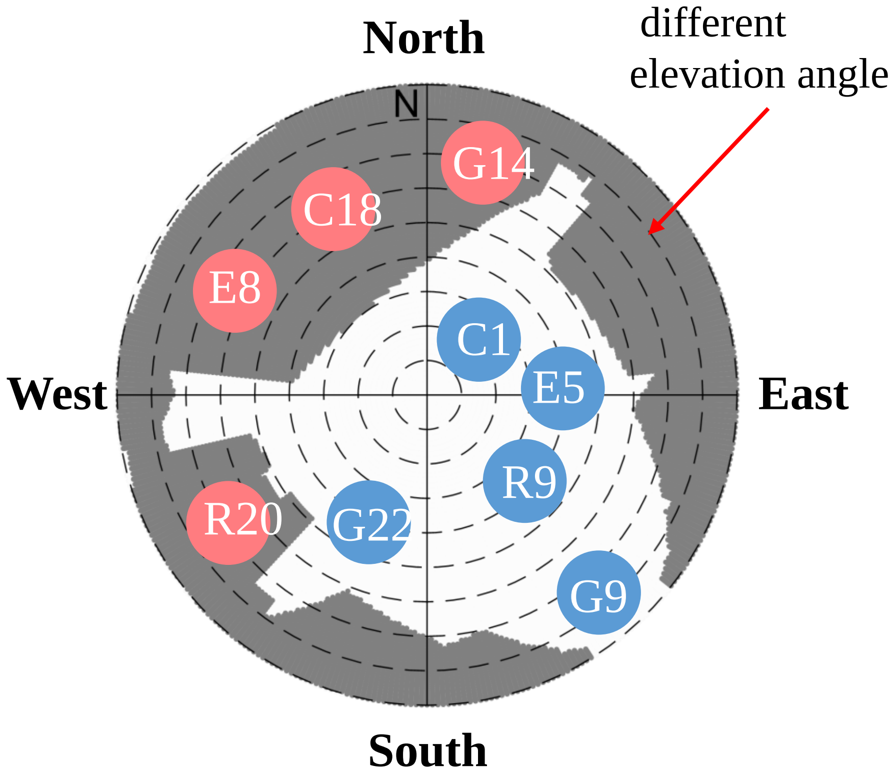
GNSS mainly providing globally referenced positioning for autonomous driving. According to a review paper[1] , NLOS is the main challenge for GNSS urban positioning.



[1]J. Breßler, P. Reisdorf, M. Obst, and G. Wanielik, "GNSS positioning in non-line-of-sight context—A survey," in *Intelligent Transportation Systems (ITSC), 2016 IEEE 19th International Conference on*, 2016, pp. 1147-1154: IEEE.

Related Work - Satellite Visibility Prediction

- Excluding satellite measurement of the LOS path blocked by buildings from GNSS positioning.
- G14, R20, E8 and C18 are detected as NLOS based on 3D building model.

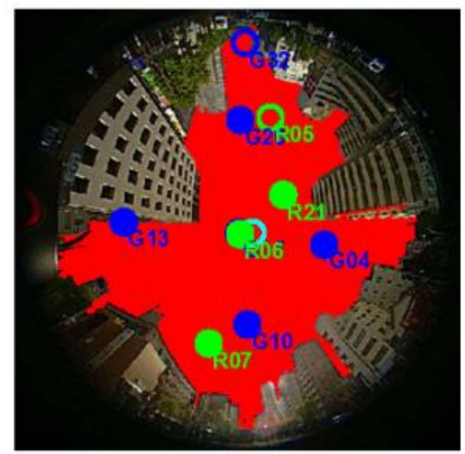


Skyplot with 3D building model (**Sky Mask**)

Related Work –Sky-Pointing Camera Aided GNSS

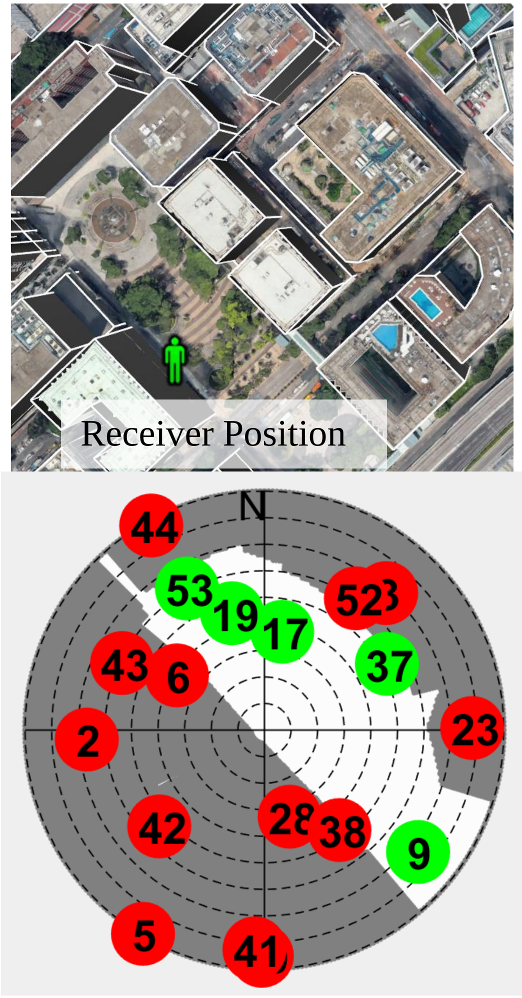
- NLOS detection using Omnidirectional Infrared Camera/Fish-eye Camera.
  (J.Meguro, et al., IEEE trans. on ITS, 2009 and T. Suzuki and N. Kubo,. ION GNSS+ 2014.)
- Excessive NLOS exclusion leads to HDOP distortion and Large Positioning Error!

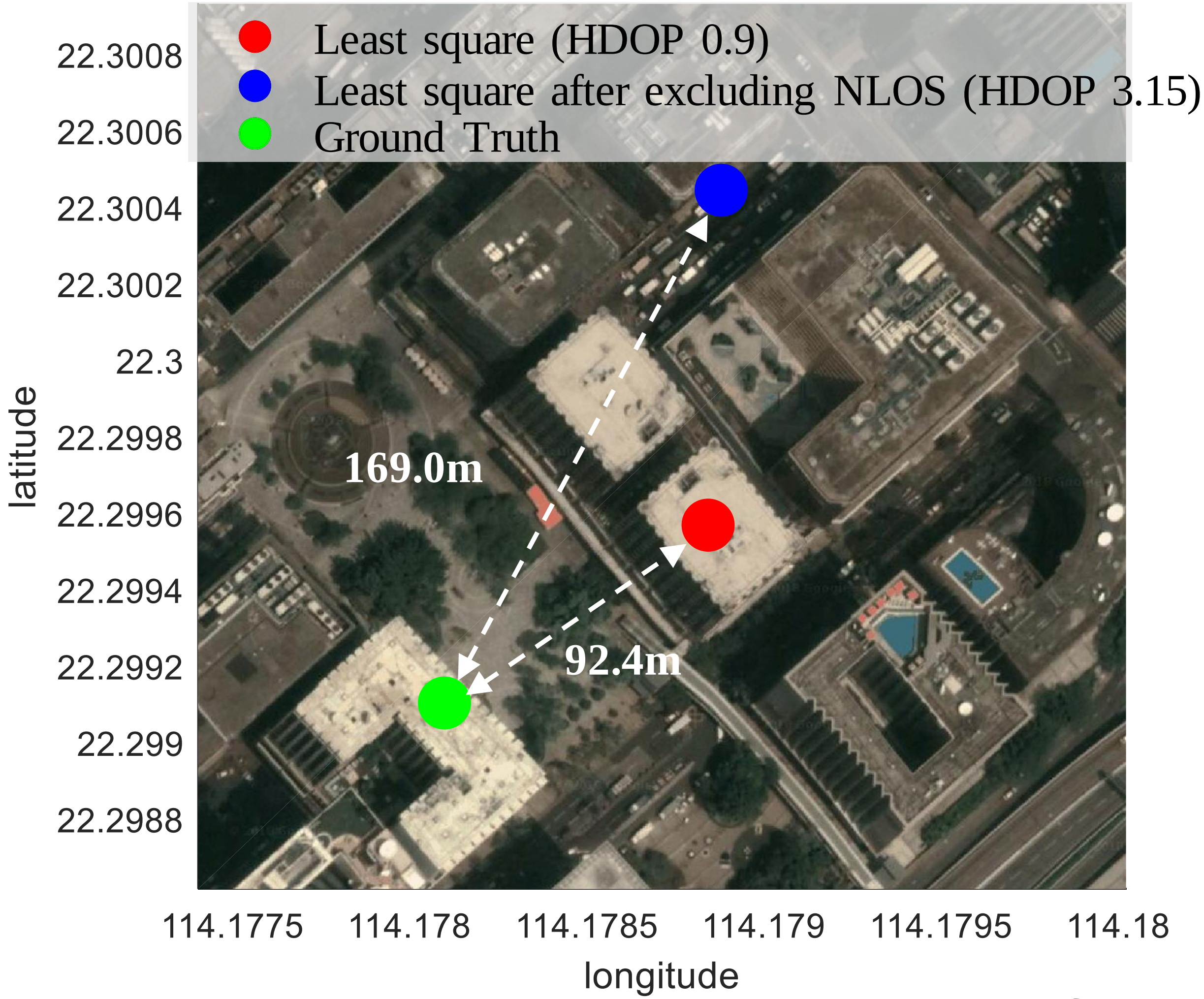
Fisheye camera



Source: T. Suzuki and N. Kubo 2014

Related Work –Sky-Pointing Camera Aided GNSS



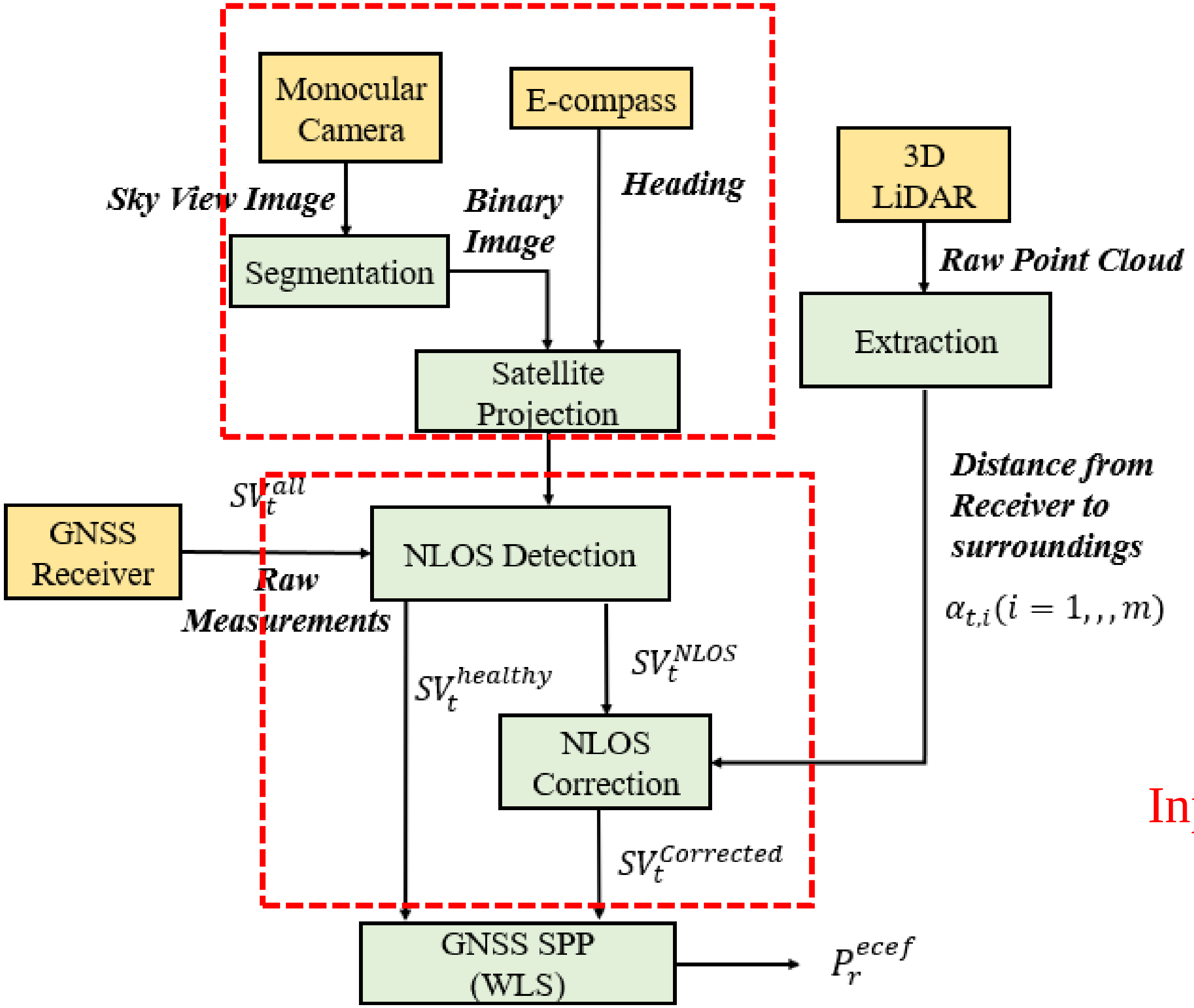


Brief Summary

Methods	Building Model	NLOS Exclusion	NLOS Correction	Prior Information	HDOP
Satellite Visibility Prediction	√	√	×	√	Increase
Camera aided GNSS	×	√	×	×	Increase
Ray-tracing based 3DMA GNSS	√	×	√	√	Not changed

Our idea: To implement sky-pointing camera and LiDAR to help the GNSS SPP for autonomous driving!

Flowchart of the proposed method



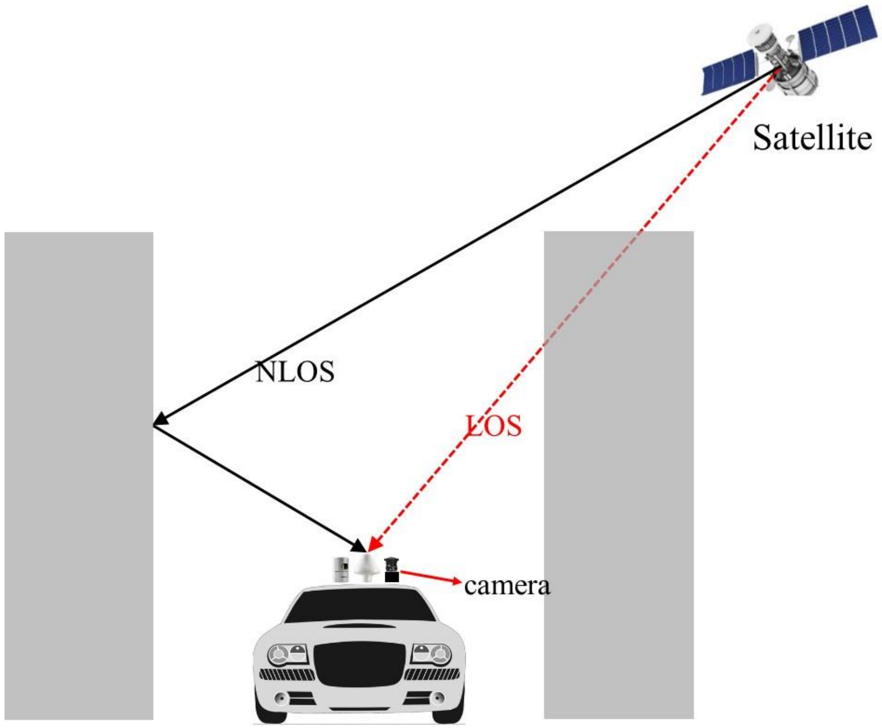
Input:

- GNSS data
- Sky View Image
- Heading
- Point Cloud

NLOS Detection using Monocular camera

To detect the NLOS signal:

- 1) Sky View Segmentation and
- 2) Satellite Projection and LOS/NLOS Classification.



Sky View Segmentation

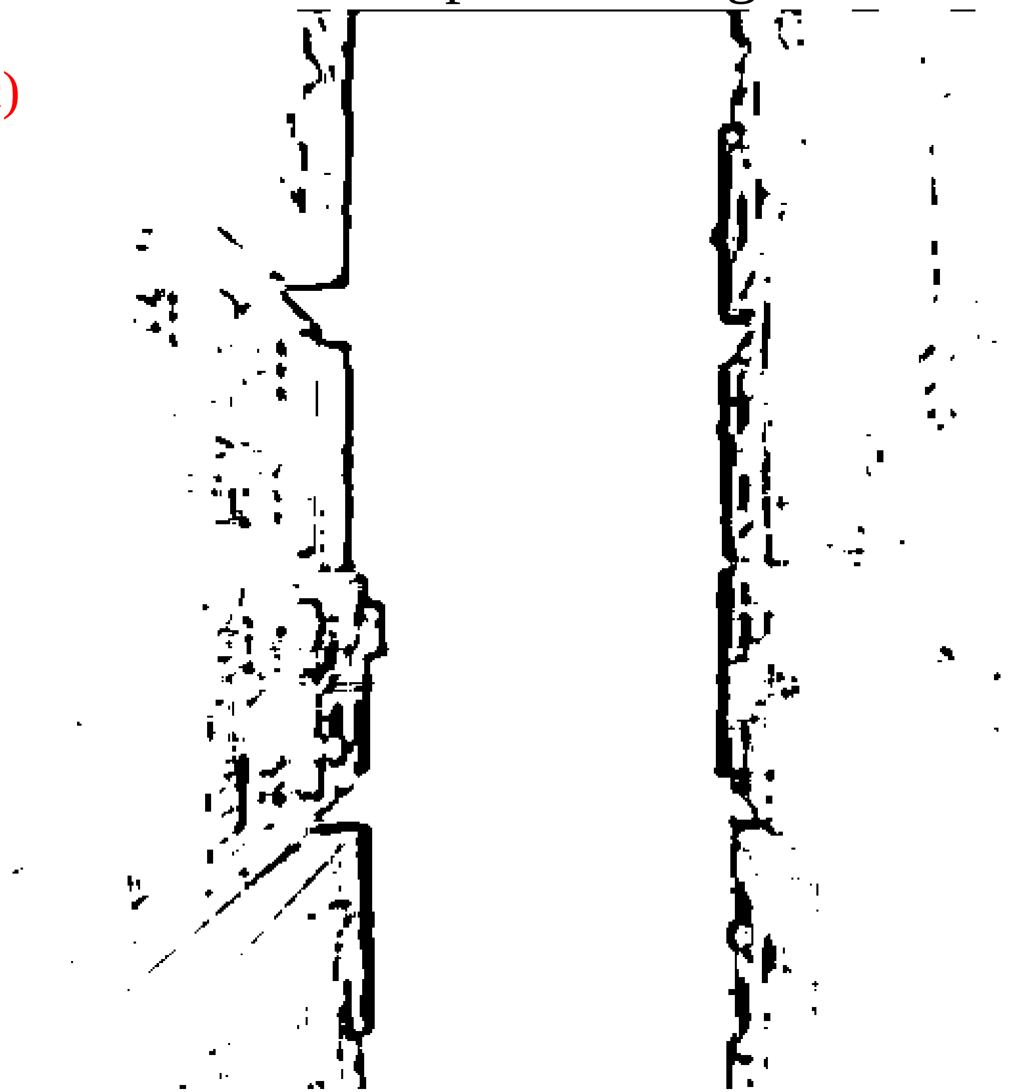
The mean mask elevation angle of buildings can go up to 50 degrees in dense urban, therefore we use monocular camera to capture the sky view image.

(a)

Sky View Segmentation

we propose to use two steps to distinguish the sky area and non-sky area:

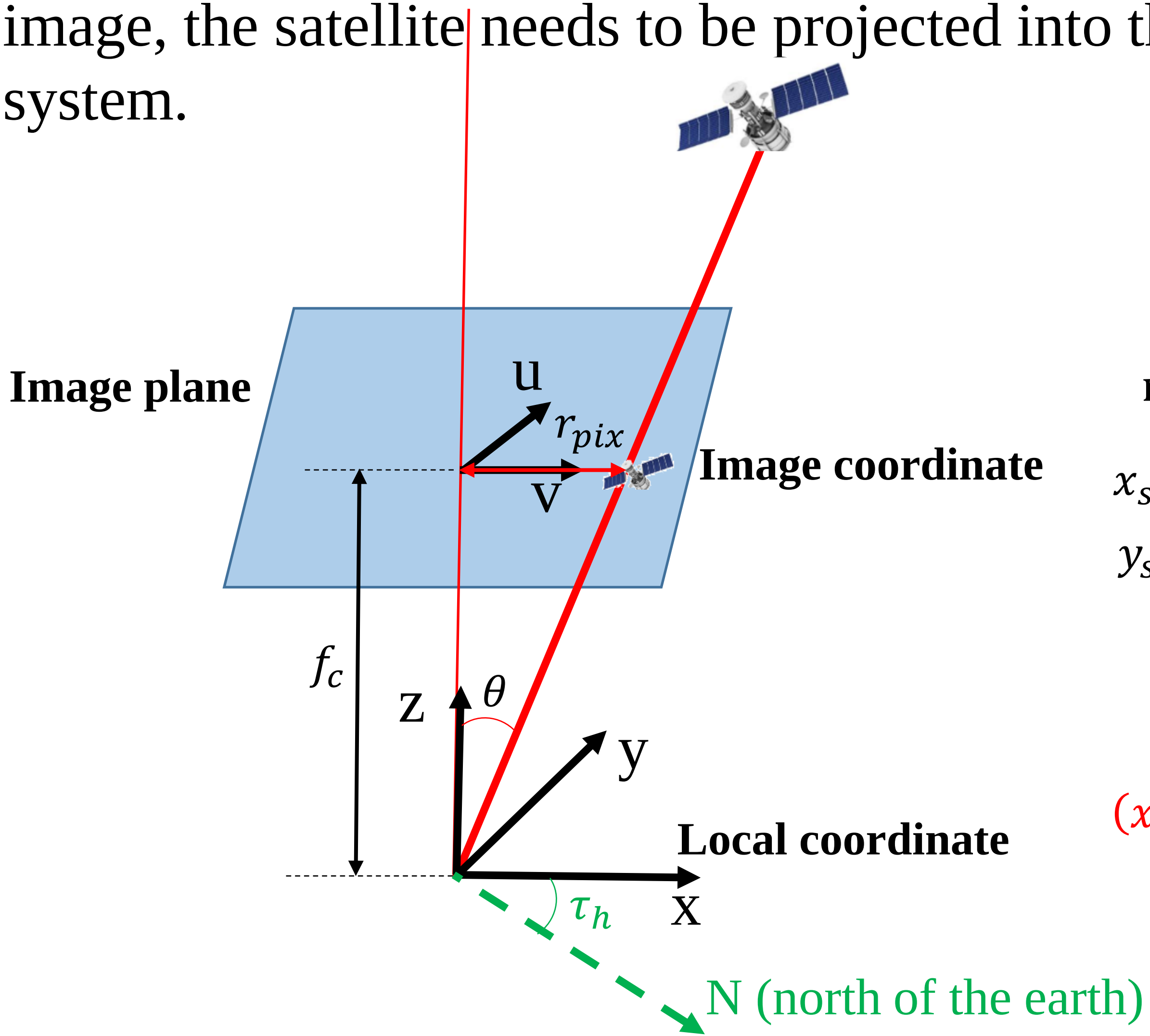
(c)



Adaptive threshold,
Median filtering
- open source library-OpenCV

Satellite Projection

To identify the satellite visibility based on the segmented sky view image, the satellite needs to be projected into the image coordinate system.



$$\theta = \frac{\pi}{2} - \emptyset_{sat}$$

$$r_{pix} = f_c \tan\left(\frac{\pi}{2} - \emptyset_{sat}\right)$$

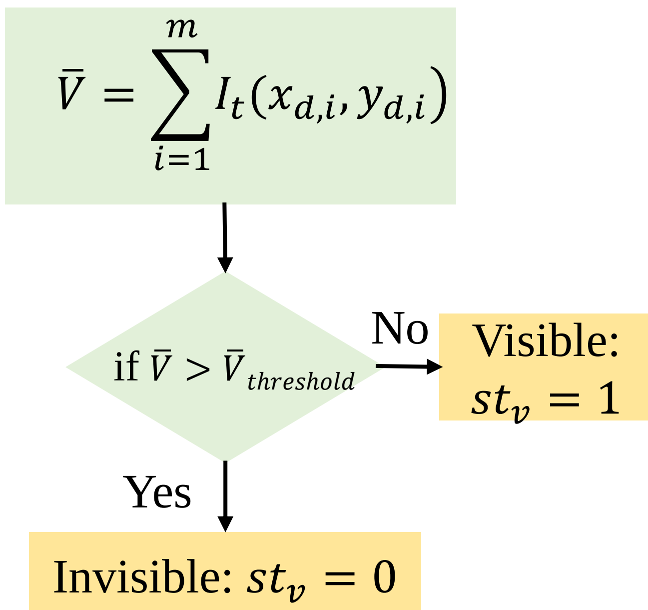
$$x_s = x_c + r_{pix}\cos(\tau_h + \alpha_{sat})$$

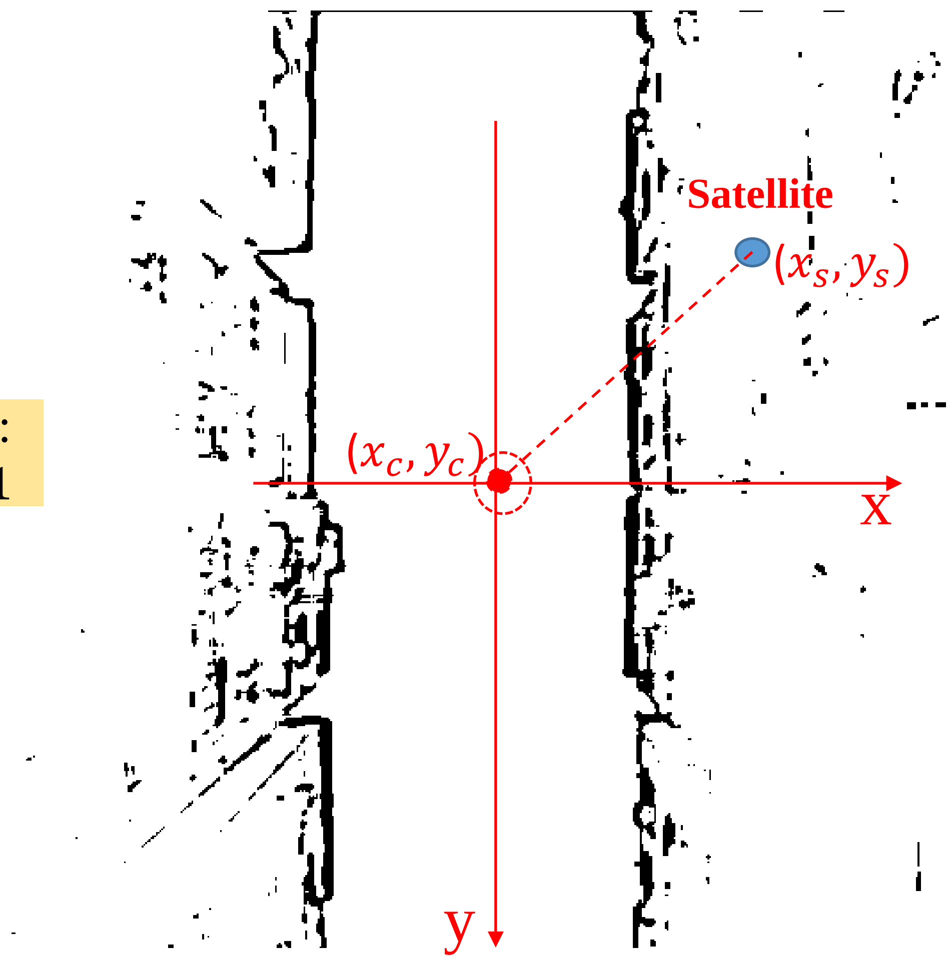
$$y_s = y_c - r_{pix}\sin(\tau_h + \alpha_{sat})$$

$\emptyset_{sat}$: elevation angle
α_{sat}: azimuth
f_c : focal length
(x_c, y_c): the center of the image
τ_h: the heading

Satellite Visibility Identification

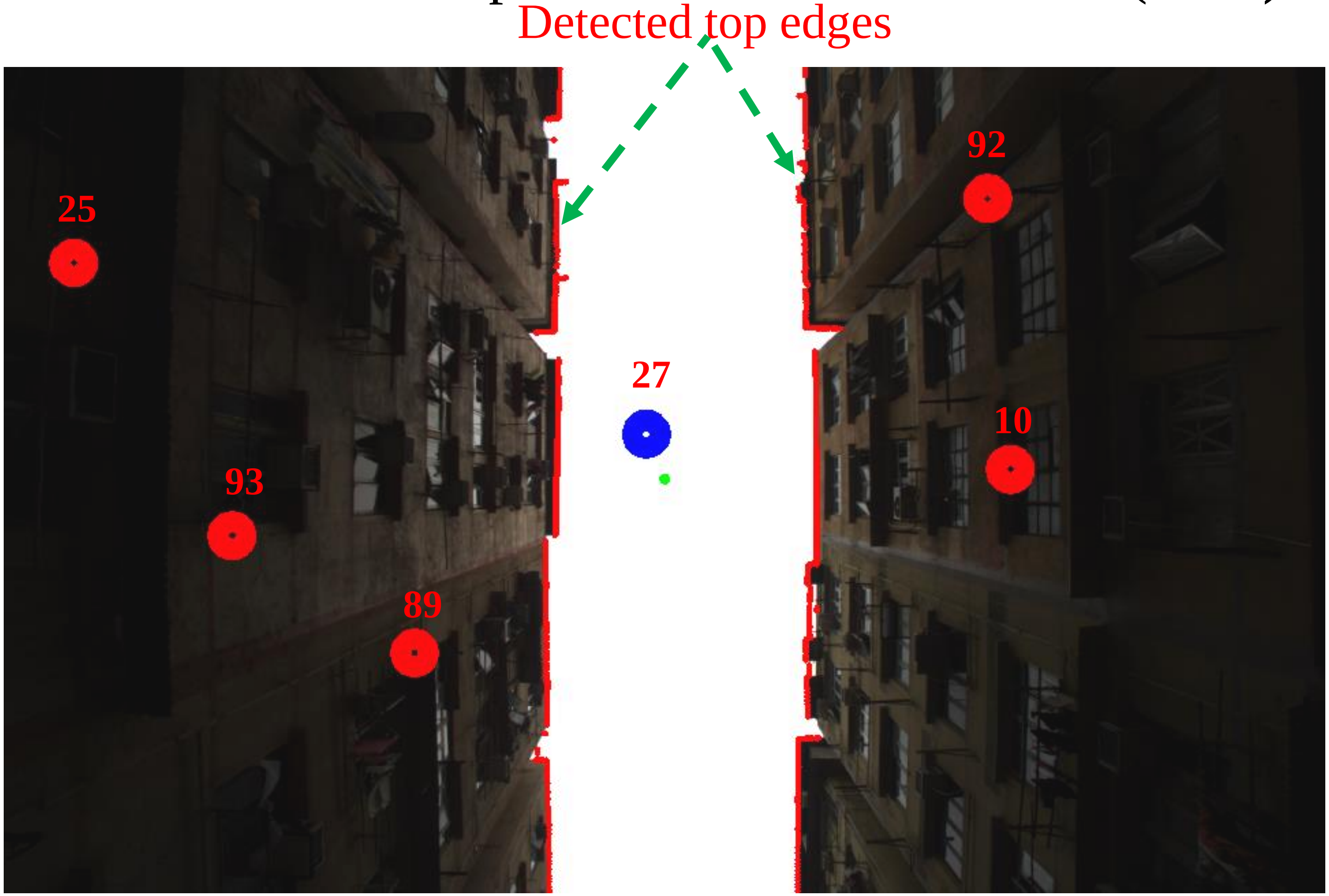
To identify satellite visibility based on the segmented sky view image and the projected coordinates.



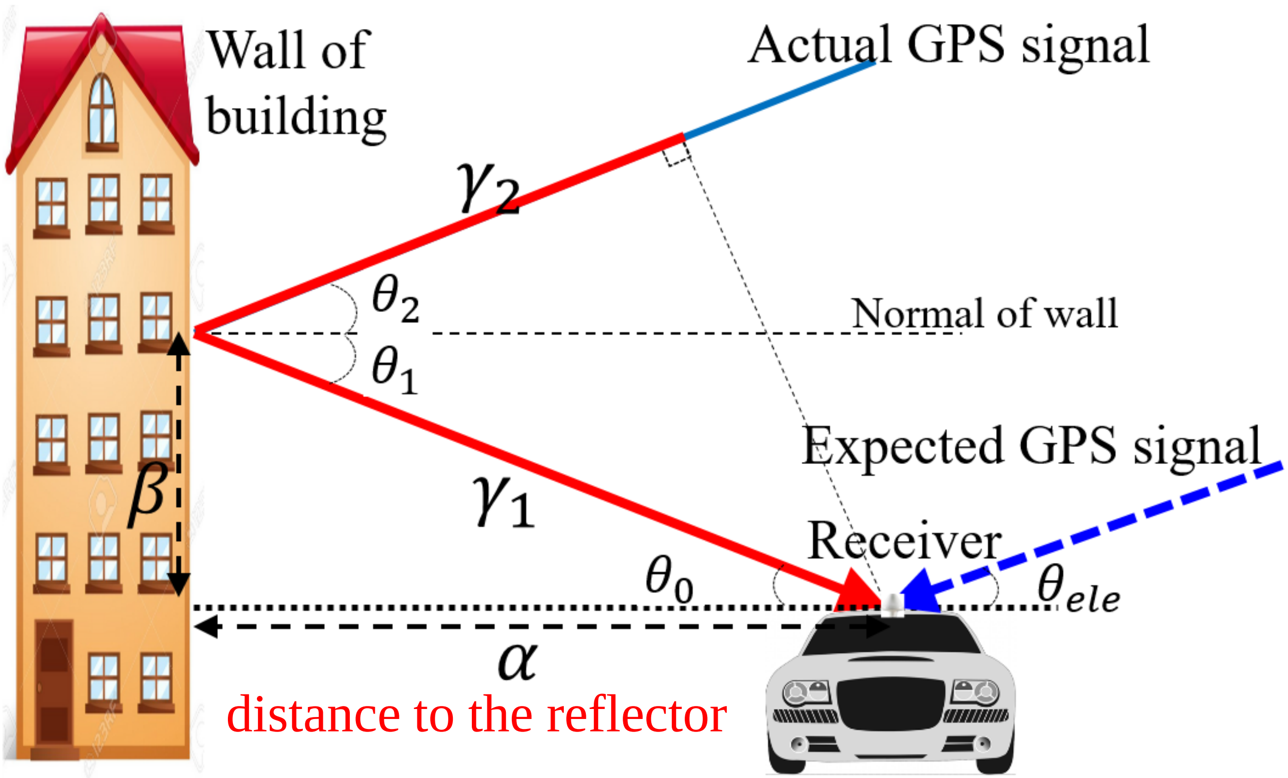


Satellite Visibility Identification

The red curve denotes the detected edge separating the sky and non-sky area. The number represents the satellite index (PRN).



NLOS Error Modeling



- $\gamma = \gamma_1 + \gamma_2$
- $\gamma_1 = \alpha sec\theta_{ele}$

$$\gamma_2 = \gamma_1 \cos(\theta_1 + \theta_2)$$

$$\gamma = \alpha\left(sec\,\theta_{ele}\,(1 + cos\,2\theta_{ele})\right)$$

L.-T. Hsu, "Analysis and modeling GPS NLOS effect in highly urbanized area," *GPS Solutions*, 22(1):1-7, 2018

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GNSS Positioning

Least Square Method

$$\hat{x} = (G^T G)^{-1} G^T \rho$$

Weighted Least Square Method

$$\hat{x} = (G^T W G)^{-1} G^T W \rho$$

To verify the effectiveness of the proposed method, three positioning solutions are compared in the experiment:

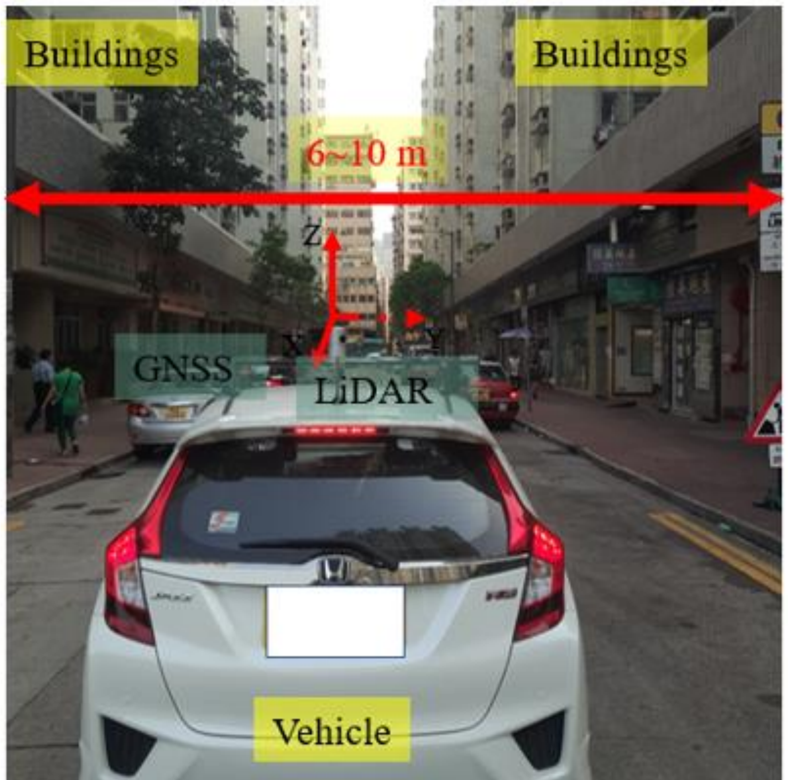
(1) WLS positioning (WLS) (goGPS)
(2) WLS positioning + NLOS exclusion (WLS-NE) (camera)
(3) WLS positioning + NLOS correction (WLS-NC) (camera+ 3D Lidar)

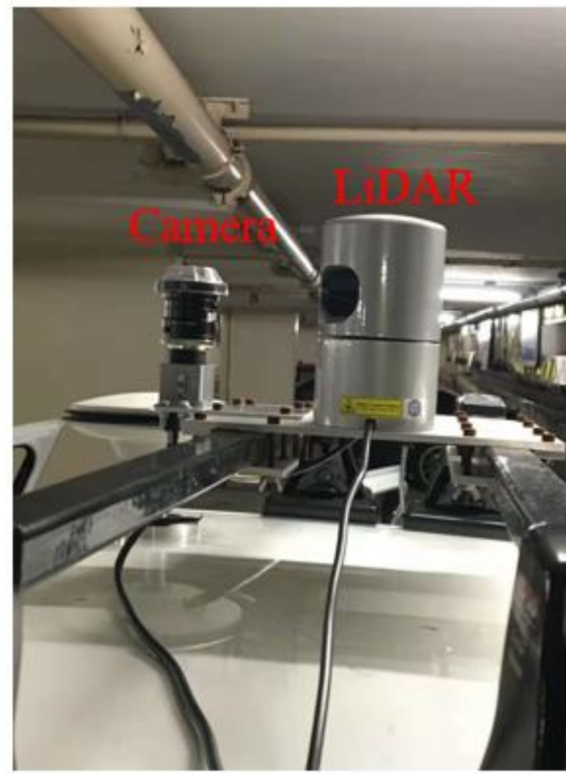
E. Realini and M. Reguzzoni, "goGPS: open source software for enhancing the accuracy of low-cost receivers by single-frequency relative kinematic positioning," *Measurement Science and technology*, vol. 24, no. 11, p. 115010, 2013.

Experiment Setup

The ublox M8T receiver is used to collect raw GPS and Beidou measurements. 3D LiDAR sensor, Velodyne 32, is employed to provide the real-time point cloud. The sky view is captured by the sky-pointing camera.

Building height: 27 meters





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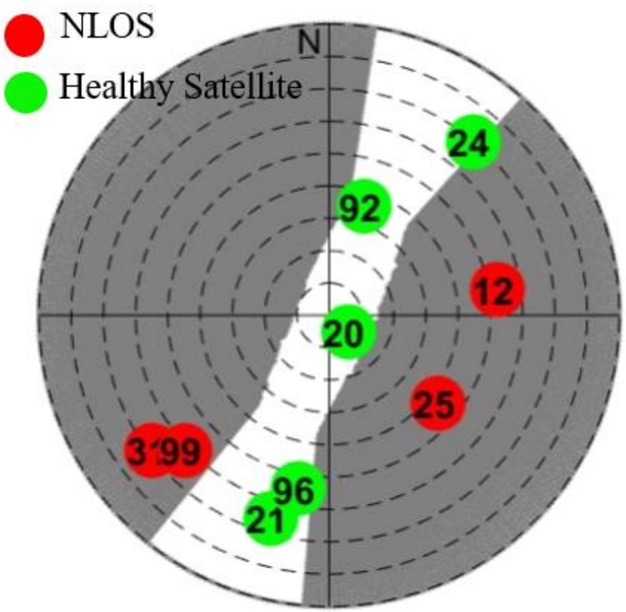
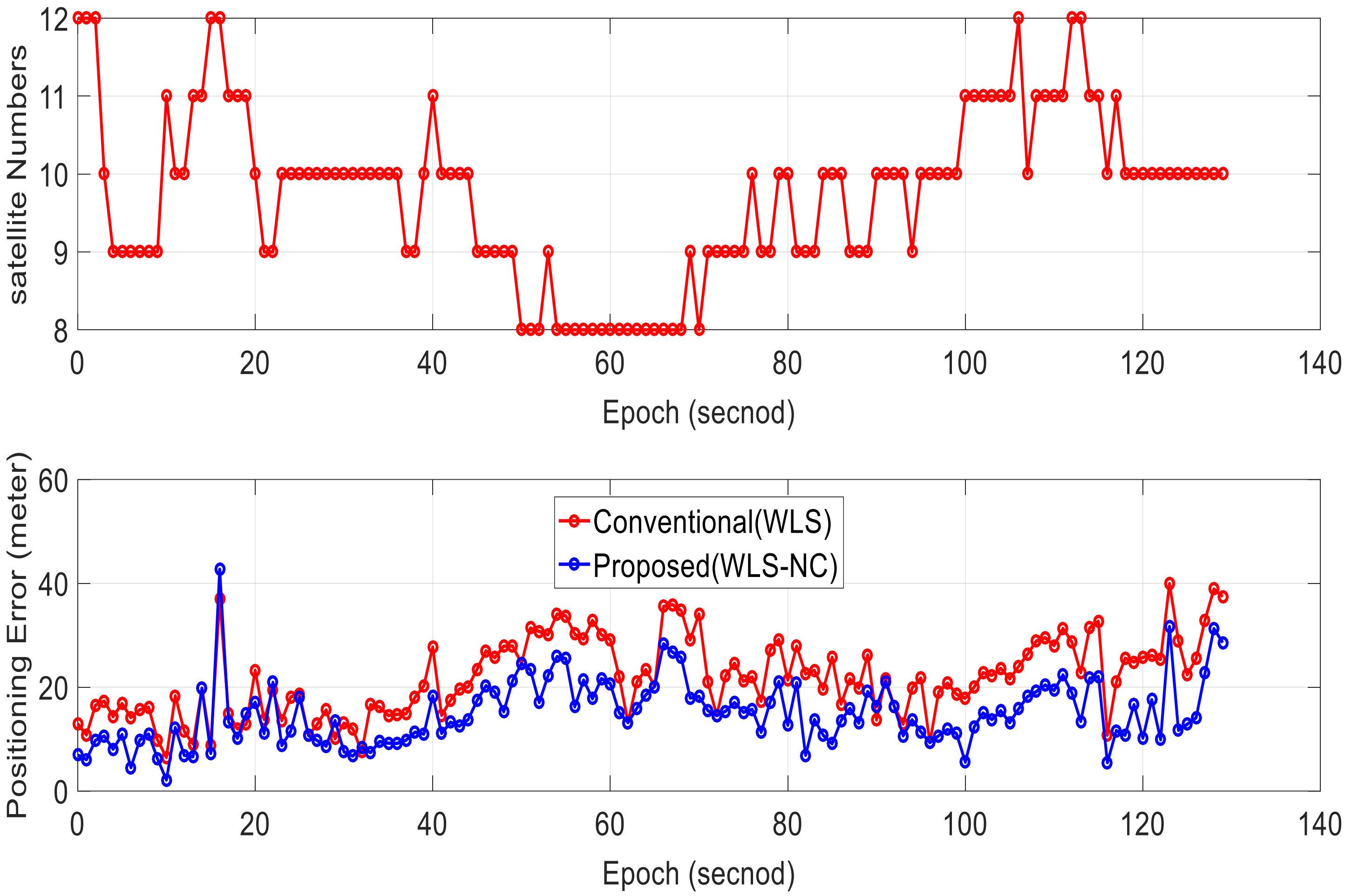
Satellites Distribution

Only 9 satellites are received, due to the blockage from the tall buildings. Almost 4 of 9 satellites are NLOS.



Experiment Result



Experiment Result

(1) WLS positioning (WLS)
(2) WLS positioning + NLOS exclusion (WLS-NE)
(3) WLS positioning + NLOS correction (WLS-NC)

All data	WLS	WLS-NE	WLS-NC
Mean error	22.01	24.99	14.96
Std	7.61	14.69	6.06
Percentage (<15 meters)	41.98%	44.62%	77.69%
Percentage (<30 meters)	95.41%	82.31%	100%
Percentage (>40 meters)	0%	10.76%	0%

(in the unit of meter)

Experiment Result

Value of corrected pseudorange (in the unit of meter)

NLOS Satellite PRN	Elevation Angle0	C/N_o	Pseudorange Correction
12	37.24°	27 dB-Hz	5.08 m
25	46.67°	19 dB-Hz	5.71 m
31	20.94°	22 dB-Hz	10.32 m
99	28.78°	24 dB-Hz	12.45 m

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Conclusions

WLS vs. **WLS-NC**

Mean: 22.01→ 14.96 meters

Std: 7.61 → 6.06 meters

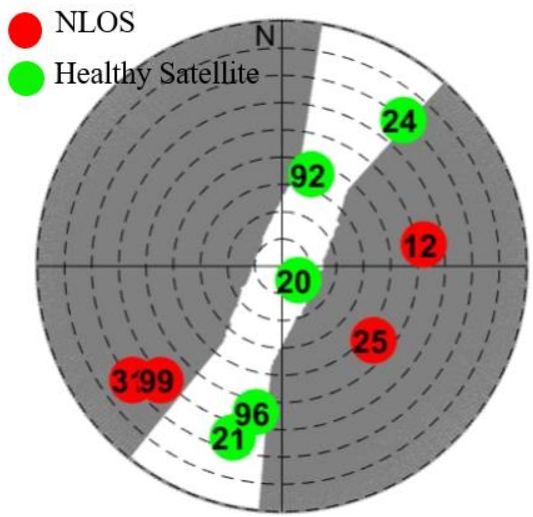
Satellite Excluded: no

WLS vs. **WLS-NE**

Mean: 22.01 → 24.99 meters

Std: 7.61 → 14.69 meters

Satellite Excluded: 3~8 Satellites



- The NLOS receptions are severe in deep urban areas. Half of the measurements are NLOS.
- Exclusion of NLOS measurement can distort the GNSS HDOP, leading to even worse positioning result.

Future Work

- Identification of the reflectors source .
- Comprehensive analysis in Hong Kong.

- Study the impact to GNSS positioning by all the potential obstacles to block the satellite signal transmission.
  - Trees, moving objects (double-decked bus) and more.

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Thank you for your attention

Q&A

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