Satellite Visibility and Geometry Analysis for GNSS Positioning in an Urban Environment

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***Abstract*—Accuracy of urban positioning depends on the quality of signals received by a Global Navigation Satellite System (GNSS) receiver that can be a combination of light of sight, reflection and diffraction signals. The more light of sight signals are received, the more accurate positioning can be achieved. To evaluate signal propagation thus availability of GNSS satellites in urban environments, a ray-tracing based modelling technique is proposed that can predict the light of sight, reflection and diffraction signals together with 3D city model. The developed techniques are validated against in-situ measurements in urban areas with different scenarios.**

Keywords— GNSS positioning; satellite visibility; signal propagation; ray-tracing; urban environment

I. Introduction

Global Navigation Satellite System (GNSS) plays a crucial role in urban positioning from which various consumer applications could benefit from. The key performance requirements of these services are availability and accuracy that depend largely on the number and geometry of the satellites visible to a GNSS receiver. Nevertheless, performance of GNSS positioning in urban environments is hindered by poor satellite availability due to the surrounding environment of the receiver that presents three major challenges in the computation of the visibility of a satellite: Firstly, tall buildings, elevated structures such as overpasses, and elevated MRT, may block signals from the satellites. Secondly, signals may be multi-reflected by flat, glass or mental surrounding surfaces. Thirdly, when signals are partially blocked by a surrounding obstacle, edge-diffraction may occur. All of these may either make the satellites invisible or dilute signals from satellites, thus make the positioning difficult and even impossible. To address the above issues, a ray-tracing based modelling technique is presented to predict satellite visibility in an urban environment by evaluating light of Sight (LOS), reflection and diffraction signals together with 3D city model. The developed techniques are also validated against online tools and in-situ measurements.

II. Methodology

The current work presents three modelling steps to evaluate the availability and Dilution of Precision (DOP) of GNSS satellites in an urban environment using ray-tracing algorithm. The first step is the development of the orbit model to compute the position of satellites, i.e., using the Simplified General Perturbations (SGP) model [1] together with the Two-Line Element Set (TLEs) data downloaded to approximately calculate the satellites' positions. The second step is to use the CityGML model to represent the urban environments, which is subsequently converted to a STL surface model. The third step is the development of an image-based ray tracing algorithm as presented in [2] to trace signals from satellites to a receiver on the earth. Both LOS and first-order reflection and diffraction are considered. With the developed model, the position of a satellite relative to a location on the earth's surface, presented by the elevation angle and the azimuth angle, is then able to be predicted for a given time. Satellites with the elevation angle larger than the mask angle are further evaluated the visibility by computing the blocking of signals in an urban environment. DOP is consequently computed using the LOS satellites.

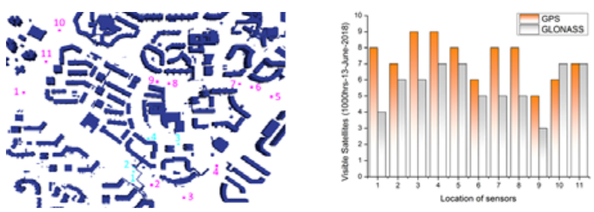
III. Validation and Results

The SGP model and the algorithm for computing the visibility and DOP are validated with the results generated by available online tools as shown in Table I without considering the urban environment, while the entire developed model is validated against on-site measurements whose details are shown in Table II. Figure 1(a) shows the site and the locations in light blue of the measurements. Location 1 and 2 are near to each other with Location 1 in the middle of the road and Location 2 near buildings. Location 3 is in a basketball court between two high-rise buildings, and Location 4 is in an open space at the foot of a tall building.

TABLE I. Comparison of results against an online tool

Observer location	Lat.: 1.367°N, Lon.: 103.833°E, Alt.: 26.824m		
Simulation time	10am, 13 Jun 2018		
Elevation Mask	15°		
GPS satellites	PRN/G: 01, 03, 08, 09, 11, 18, 22, 23, 27		
GLONASS satellites	PRN/R: 5, 6, 16, 18, 19, 20		
Optimum satellites	G01,G08, R6, R16		
DOP (our code)	GDOP: 2.82	PDOP: 2.54	TDOP: 1.21
DOP (*CalSky*) [3]	GDOP: 2.82	PDOP: 2.55	TDOP: 1.21

Comparisons of visible satellites between the results predicted and these measured are shown in Figure 2 partially. The mask elevation angle is set to 15°c. An observation can be made from the results that R10 is visible in the simulation results, but invisible in the measurements. It may be due to either it was not working or the mobile phone was not able to detect it. It can also be observed that there is very good agreement for Location 1-3 except for G12 in Location 1 and G32 in Location 3. For Location 4, the agreement is fair, which is expected as it is at the foot of a tall building, where edge-diffraction very likely occurs. Simulation results show that signals from the unmatched satellites are blocked by buildings, which however can be detected by the mobile phone. It may be due to two possible reasons: one is the discrepancies between the 3D geometrical model used and the real environment, the other is edge-diffraction that is not included in the simulations due to the difficulty to automatically extract edge information from the 3D model. The observation that the location of the blocking point for G12 in Location 1 is near the edge of the building may infer that the discrepancies of geometrical model may be the main cause of the unsatisfactory result in Location 1. Meanwhile, analysis results made for Location 4 show that there are edge-diffraction signals, which may be the main cause of the fair results there. Figure 1(b) shows the availability of GPS and GLONASS satellites at the locations indicated in Figure 1(a) in pink color. The results are satisfactory as there are few urban canyons. However the varieties of the results among the different locations indicate the effects of various urban morphologies on satellite availability.



(a) Site and locations of the measurement (b) Satellite visibility

Fig. 1. Site and locations of the measurement

TABLE II. INFORMATION OF THE MEASUREMENTS

Location No.	Latitude (degree)	Longitude (degree)	Altitude (meter)	Local time (9-Oct-2018)
1	1.338204619	103.738599000	23	15:15:41
2	1.338366369	103.738613700	23	15:36:47
3	1.339200000	103.740111000	26	16:13:18
4	1.339385000	103.739099000	25.5	16:03:11

IV. CONCLUTIONS

A ray-tracing based modelling technique is presented in this work to predict the satellite visibility in an urban environment. The developed techniques are validated against in-situ measurements. Observation can be made from the simulation results that the visibility of satellites to a receiver in an urban area is strongly influenced by the receiver's surrounding environment. Meanwhile, the validation results reveal that the reliability of the simulation results is affected by the accuracy of the geometrical models and the algorithms where both multi-reflection and edge-diffraction are suggested to be considered. The developed model is being used to analyze the visibility and DOP of GNSS satellites on roads island-wide in Singapore. Laborious and time-consuming in-situ measurements are therefore avoided. With the simulated results, places where the satellite visibility or DOP is poor can be identified and necessary measures can be taken accordingly.

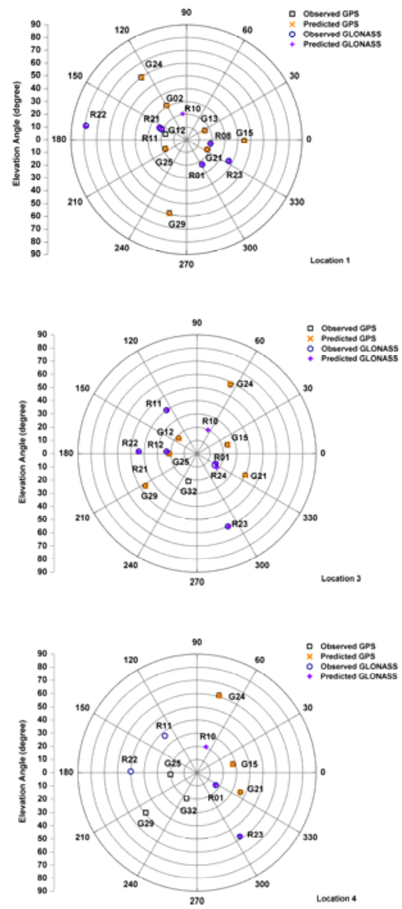


Fig. 2. Satellite visibility comparison

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