Framework and Performance Evaluation of a Ray Tracing-Software Defined Radio Method for GNSS Positioning in an Urban Canyon Environment

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BIOGRAPHIES

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ABSTRACT

In this study, GNSS receiver observables obtained from actual and emulated GNSS signals will be compared and evaluated. The actual GNSS signals are captured in an urban canyon area in Tokyo downtown, while the emulated GNSS signals are synthesized by a software-defined radio (SDR) device using a ray tracing method . The ray tracing method is used to estimate multipath profiles, including the amplitude, code delay, and phase shift in a 3D building map environment. The multipath profiles are then processed to synthesize GNSS signals using an SDR device.

1 INTRODUCTION

In recent years, positioning techniques based on Global Navigation Satellite System (GNSS) are used in a wide spread of applications such as car navigation systems and smart phones. Furthermore, the demand for high-precision positioning is growing rapidly in the areas of precision agriculture, UAVs, and information-oriented construction activities.

In GNSS positioning, various factors between the satellite and the GNSS receiver can degrade the GNSS signal and thus affect positioning accuracy. Urban areas are particularly susceptible to multipath errors due to the effects of the shade and reflection from the surrounding buildings, which causes a large deterioration in positioning accuracy [1]. It is important to study these influences theoretically to investigate and verify countermeasures against multipath errors.

In this study, the effects of the multipath signals to the GNSS receiver observables will be evaluated. In many cases, positioning algorithms of the commercial GNSS receivers are not disclosed. For this reason, it is difficult to create a numerical GNSS receiver model emulating the internal signal processing. We therefore use synthesized GNSS signals from an SDR device as input to an actual GNSS receiver. Moreover, it is appropriate to generate the GNSS signals considering the multipath radio wave propagation situation. By utilizing an SDR device [2], flexible generation of GNSS signals with multipath effects is possible. For the effective prediction of multipath radio wave propagation in urban areas, a ray tracing method [3] [4] using 3D building models is used. The ray tracing method is used to estimate multipath profiles, including the amplitude, code delay, and phase shift due to the surrounding building environment.

Chapter 2 discusses the framework of the GNSS signal emulation using our ray tracing and software-defined radio (RT-SDR) method. Chapter 3 evaluates the accuracy of our framework with actual GNSS measurements. Finally, Chapter 4 concludes our study.

2 FRAMEWORK OF GNSS SIGNAL EMULATION

2.1 Urban canyon environment

As shown in Fig. 1, in an urban canyon area, the signal transmitted by the GNSS satellite is reflected and/or diffracted by the buildings. Fig. 1 shows 2 scenarios namely line-of-sight (LoS) and non-LoS (NLoS) in which no direct wave is visible. Even for the LoS scenario, reflection and/or diffraction paths can exist, and these signals become the multipath signals. These multipath scenarios depend on the position of the satellite, the receiver, and the surrounding building environment.

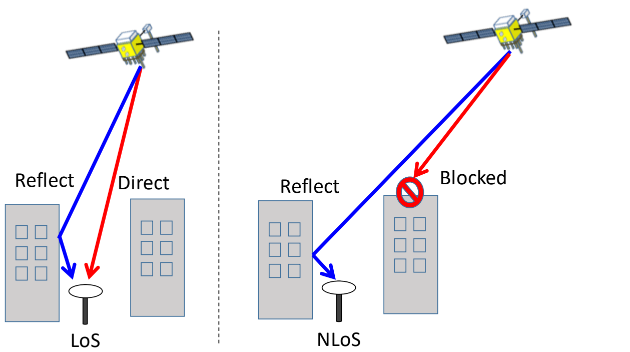

Figure 1 – LoS and NLoS scenario in an urban canyon environment.

2.2 Emulation of GNSS signals in an urban canyon environment

Although the positioning errors due to the multipath effects depend on the signal processing and positioning algorithms inside of the GNSS receiver, the algorithms used in commercially available receivers are not always disclosed. Therefore, it is required to take the GNSS receiver under test to the field to evaluate its performance.

Alternatively, it is possible to evaluate the GNSS receiver performance in a controlled laboratory environment by using a GNSS signal generator [5]. However, it is challenging for the signal generator to emulate realistic multipath effects created by the complex structure of urban area buildings.

In this study, we estimate multipath profiles by considering the influence of 3D urban buildings using ray tracing method, and generate realistic GNSS signals using an SDR device. This process is outlined in Fig. 2.

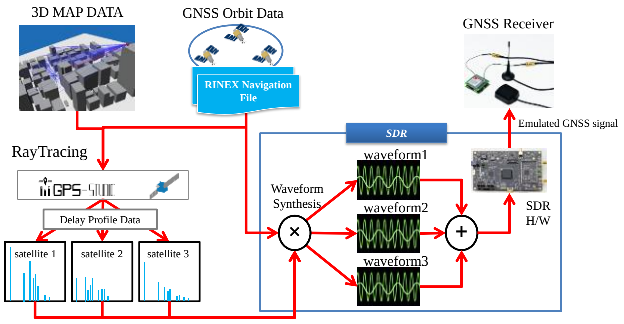

Figure 2 – Framework of RT-SDR Method

2.3 Multipath profile using the ray tracing method

Ray tracing was a method originally used for optics simulation in 3D computer graphics (CG). However, in recent years, it has also been used for radio wave simulation. Fig. 3 shows an illustration of radio wave propagation using the ray tracing method.

In the radio wave propagation simulation of GNSS signals using the ray tracing method, the position of the GNSS satellite is first calculated from the receiver position, date, and orbital parameters of GNSS satellites contained in the navigation messages. The radio wave propagation paths from the position of the GNSS satellite to the position of the receiver, which includes reflection and/or diffraction on the surfaces of the buildings, are then obtained. The propagation loss, phase rotation, and receiver antenna gain are then considered to estimate the multipath profile at the time of reception. In this study, GPS-Studio software [6] developed by Kozo Keikaku Engineering is used for both satellite position calculation and ray tracing.

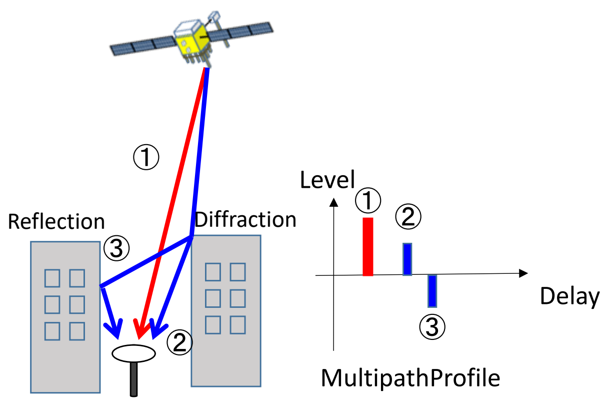

Figure 3 – Radio propagation analysis using ray tracing method and its multipath profile result.

The detailed process of synthesizing GNSS signals using the simulated multipath delay profile is described in the next subsection.

2.4 Emulation of the GNSS signal using SDR

SDR is a system that combines the RF front-end of a wireless system with software that carries out the signal processing of the upper layer. A general-purpose RF front-end [2] that can be used for various wireless systems is commercially available. In this study, SDR-SAT [8], which is an extension of gps-sdr-sim [7], is used as the GNSS signal generation software. For synthesizing a large number of multipath signals in real time, we used NVIDIA GTX1080 GPU to accelerate the GNSS signal generation.

In SDR signal generation, the position of each GNSS satellite is calculated from the receiver's position, date, time, and the orbital parameters contained in navigation messages. This is also the case in ray tracing. The GNSS signal transmission time can be obtained by the reception time minus the propagation time of the direct wave.

The GNSS signal, such as the signal transmitted from the GPS satellite, is modulated according to the interface specifications [9] by the carrier wave, ranging code and navigation messages. Fig. 4 illustrates this process.

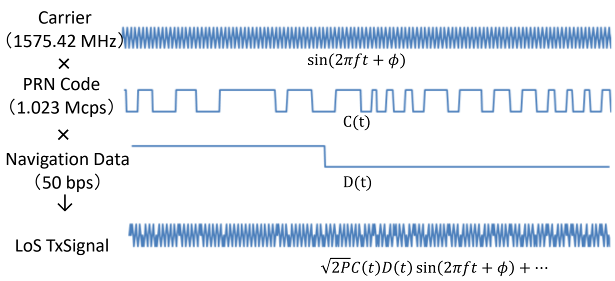

Figure 4 – GNSS signal generation (GPS) .

In order to synthesize the GNSS signal with multipath effects, the amplitude, phase shift, and code delay of each path in the multipath profile simulated by the ray tracing method are superimposed on one another. An illustration of this process is shown in Fig. 5.

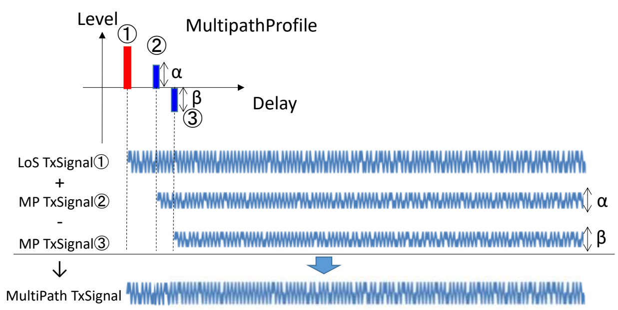

Figure 5 – Generation of satellite multipath signal with GNSS.

Furthermore, by superimposing the GNSS signals of all the visible satellites, the multiplexed GNSS signal at the specific receiver location is generated for every epoch. In the GNSS signal generation in this study, the ionospheric and the tropospheric errors are considered. Therefore, the error sources included in the synthesized signals are from the multipath and the clock bias of the SDR device and the ionospheric and the tropospheric errors.

While the reference clock mounted on a typical GNSS satellite is a very stable atomic clock, the clock mounted on the SDR is merely a temperature compensated crystal oscillator (TCXO), which generates a larger signal jitter. However, since this jitter is similarly added to the signals of all the satellites in the SDR signal generation, it can be considered together with the clock error of the receiver and does not have a large adverse effect on the position calculation.

2.5 GNSS signal quality evaluation method

The GNSS signal generated by the SDR is fed to the receiver through the RF cable, and the GNSS receiver output observed information such as pseudorange and signal level are evaluated.

In the simulation process, since both the true values of the receiver position and the characteristics of the multipath signals are known beforehand, the quality of the GNSS signal can be evaluated by comparing the observations obtained by the receiver and computed from the true values.

In this study, the signal strength and the positioning result are used to evaluate the GNSS signal quality.

3 SIGNAL EMULATION PERFORMANCE

In order to verify the accuracy of the emulated GNSS signal quality in urban areas using the proposed method in this study, we first confirm generated GNSS signal quality under open-sky environment and then we compare observation information obtained from a real environment and emulated observation information obtained using the ray tracing method and a prototype SDR module.

3.1 Evaluation under open-sky environment

In this evaluation, the commercially available u-blox M8T was used as the receiver. To check the signal quality of RT-SDR method, we generated two GNSS observation data with RT-SDR method. One data is for base station and the other one is for the rover. We have done RTK-GNSS positioning with RTKLIB [12] to check signal accuracy.

Fig. 6 shows positioning result obtained from two observation data's post processing result with RTKLIB. We used continuous method and ratio test's threshold with 3.0.

Figure 6 – RTK positioning result for opensky

As a result of this evaluation, we got 60% RTK FIX solution. It was confirmed that the signal quality is not stable, and some miss FIX solutions were observed using this prototype. We therefore need signal quality improvement in GNSS phase simulation.

3.2 Evaluation under urban canyon environment

A GNSS receiver [10], installed with the Position and Orientation Systems for Land Vehicles (POSLV) [11] is used to obtain measurement data for comparison with the emulated results. The actual GNSS measurements were collected in Hibiya district of Tokyo, Japan, and the course of the vehicle is shown as a yellow line in Fig. 7. In the following evaluation, we used 30 minutes of measured data, including 3 laps along the measurement course. For kinematic positioning evaluation, the GNSS reference station placed on the roof top of the Etchujima building is used.

Figure 7 – Measurement route and buildings used for simulation. (Aerial photo: Geographical Survey Institute Map KML)

In addition to the reference values of the receiver position acquired by the POSLV, a commercially available 3D building map is used to perform a ray tracing simulation, and the synthesized GNSS signal is generated by the SDR. The building models used in the simulation are the gray objects shown in Fig. 7, and the simulation course is the same as the POSLV route.

Since 3D building data do not include any vegetation, traffic signs, pedestrians, or moving vehicles, these are not considered in the simulation. Table 1 shows the ray tracing specifications for the multipath profile estimation.

In the following evaluation, we used a low-cost receiver [13] and a low-cost RF-frontend [2] for focusing on flexibility and inexpensiveness of experimental equipment.

Table 1 – Raytracing settings.

Setting	Value
Frequency	1.575 GHz
Material	concrete
Propagation paths considered	direct path single reflection single diffraction single reflection and single diffraction double reflections
Propagation path search method	ray imaging

Table 2 shows the SDR specifications for the signal generation.

Table 2 – SDR settings.

Setting	Value
Frequency	1.575 [GHz]
RF Frontend	Blade RF x40
Sampling rate	26 [MHz]
OS	Windows 10 64bit
CPU	Core i7 7700
GPU	NVIDIA GeForce GTX1080
GNSS Receiver	u-blox NEO-M8T

In the RT-SDR method of this paper, ray tracing was calculated beforehand without real-time processing, but the GNSS signal synthesis by the SDR was processed in real time.

3.3 Evaluation of signal level

In this evaluation, the LoS and NLoS scenarios are classified using the ray tracing results. Actual measured values of SNR and the values observed from the RT-SDR method are compared.

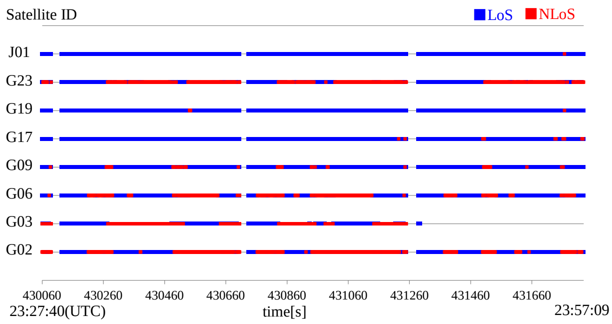

Figure 8 –Los/NLos time-series variation

LoS / NLoS of each satellite estimated by simulation along the measurement is shown in Fig. 8. It is noted that J01 in this figure shows QZSS (Quazi-Zenith Satellite System).

According to the result of the ray tracing simulation, satellite G17 is classified into LoS scenario because of its longer LoS time period (blue dots more than red dots). With similar classification method, the satellite G23 is classified as NLoS scenario.

3.3.1 Evaluation of Ray tracing Result

Fig. 9 shows SNR values of satellite number G23 obtained from the actual GNSS signal and the ray tracing method. In this simulation, we estimate SNR value from simulated received level. We set received level of -170 [dBm] from ray tracing as SNR of 0 [dB].

The signal level has the same trends except for north west areas in the vehicle route in each lap. These areas have many trees in the road side and seems to be obstacles.

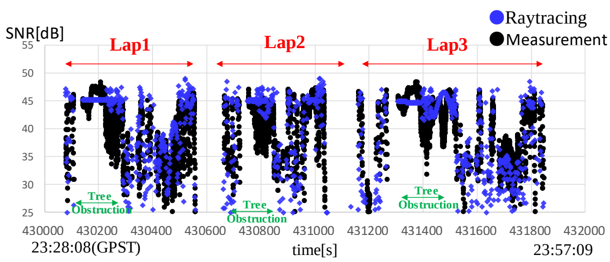

Figure 9 –SNR time-series variation of variance (LoS)

Simulating tree effects is our future work in ray tracing. Further simulation accuracy improvement is expected.

3.3.2 Evaluation of LoS scenario satellite

Fig. 10 shows SNR values of satellite number G09 obtained from the actual GNSS signal and the RT-SDR method. The actual measurement values fluctuate up and down and it seems that Rayleigh fading is caused by the surrounding buildings and traffic environment.

The signal level has about the same intensity, and the error is about 5 [dB]. The RT-SDR method shows a stable received signal level because the 3D building map does not contain small objects such as trees and street lamps.

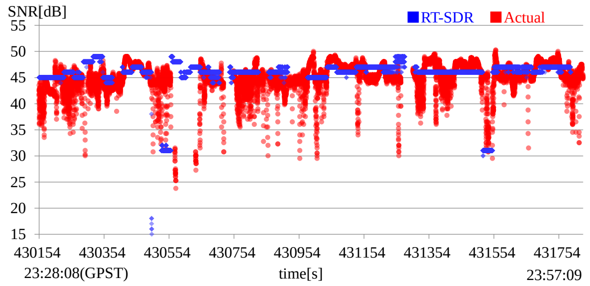

Figure 10 –SNR time-series variation of variance (LoS)

3.3.3 Evaluation of NLoS satellite

Fig. 11 shows SNR values of satellite G23 obtained from the actual GNSS signal and the RT-SDR method. Although the signal level can be roughly simulated, when reproduced by the RT-SDR method, fluctuations are small. The result of the RT-SDR method shows a value close to the maximum value or the minimum value of actual measured values fluctuating up and down.

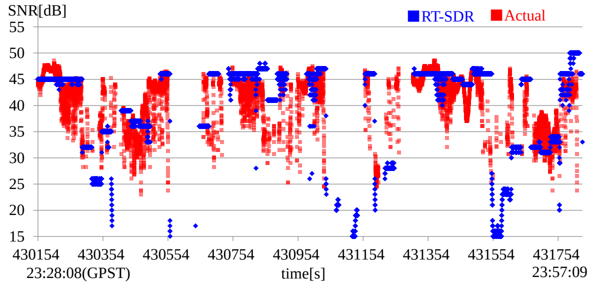

Figure 11 –SNR time-series variation of variance (NLoS)

3.3.4 Summary

Based on the above evaluation, it is difficult to perform accurate prediction of SNR change due to fading. On the other hand, it was shown that signal level simulation is possible in both the LoS/NLoS environments by the RT-SDR method.

3.4 Positioning Result

In this evaluation, the single, differential, and real-time kinematic (RTK) positioning results obtained from the POSLV and RT-SDR method are compared. All the positioning results are computed as post-processing using RTKLIB . Table 3 shows the parameter settings used in the post-processing computation.

Table 3 – Positioning settings.

Setting	Single/ DGPS /RTK
Satellite System	GPS+QZS L1
Measurement Period	1 Hz
Elevation Mask	15 deg
Ionosphere Correction	no
Troposphere Correction	no
SNR Mask	30 dB
chi-square test	use
Calculation Method	Continuous /Ratio test=3.0

Fig. 12 and Fig. 13 show the single, differential, and RTK positioning results, respectively. Table 4 summarizes the fixing rate (percentage of positioning results in measurement period) of each positioning method.

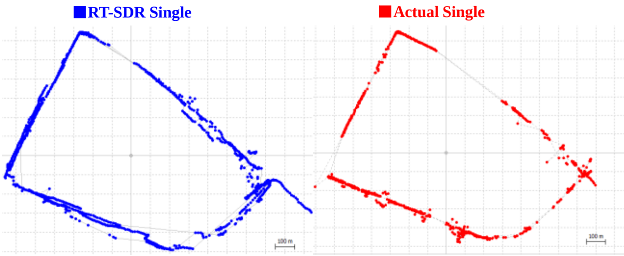

Figure 12 –Single positioning result

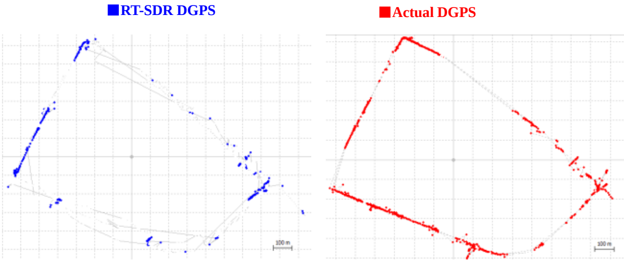

Figure 13 –Differential positioning result

Table 4 – Positioning result of measurement

Setting	Single	DGPS	RTK(FIX)
Fixing Rate of RT-SDR	80.4%	35.2%	-- %
Fixing Rate of Actual	60.5 %	56.9 %	-- %

The actual positioning fixing rate and the fixing rate of RT-SDR method positioning shows some difference.

In single positioning, fixing rate of RT-SDR is better than actual measurement. But for DGPS positioning, we obtained a different trend.

In the above evaluation, we carried out RTK-positioning, but due to insufficient number of satellites, the correct FIX solution of RTK positioning by RT-SDR method was not obtained. Likewise, correct FIX solution of RTK positioning by actual measurement data was hardly obtained.

We partially confirmed that it is possible to evaluate the trend of fixing rate change with positioning method in urban areas using RT-SDR method. In order to confirm the statistical validity, it is necessary to analyze more data and more environment.

4 CONCLUSION

In this study, a new low-cost RT-SDR method framework is proposed and the GNSS receiver outputs (signal level, positioning results, etc.) using this prototype are compared with actual measured values.

We confirmed that it is possible to generate the GNSS observation information including multipath error with RT-SDR method.

The future works of this RT-SDR method include improving accuracy of emulation (time synchronization to GPST, multipath signal emulation quality of RT-SDR, etc.) and functional improvements such as including multi GNSS (GLONASS/ BEIDOU/ GALILEO) and multi frequency (L2, L5, L6).

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