Multi-path simulation for satellite-based positioning systems using 3D digital map of urban area

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Abstract: Recently, DGPS or RTK-GPS techniques enable us to use satellite based positioning systems with high accuracy. But in urban area, navigation systems suffer from problems such as signal blockage by high-rise buildings, multi-path problems, and so on. So we have to know numbers of visible satellites and quality of signals received at the ground level in urban area as accurate as possible.

In this paper, we developed a simulation system called LoQAS [Location service Quality Assessment System, 2002, the University of Tokyo] which can simulate numbers of visible satellites and DOP values using accurate satellite orbital data and 3-D digital map. In this time, we evaluated this system and extended it to deal with reflected signals to assess multi-path problems.

Keywords: GPS, GNSS, Simulation system, 3-D map

1. Background

Recently, as an essential tool for GIS services, postioning services are getting more and more important. Especially, satellite-based positioning system is the most popular technology because of the real time and accurate positioning ability. However, the ability of satellite-based positioning system is highly degraded by signal intersections by buildings or multi-path problem in urban area although we do need accurate positioning services there. In such a situation, simulation of satellite-based positioning system in urban area is quite important.

2. Objective

In this study, we evaluate a simulation system doing a experiment and develop it. The system can simulate direct signal from navigation satellites and delineate the distribution of the numbers of visible navigation satellites and DOP values. We improve the system to simulate the distribution of reflected signals to assess the effects of multi-path problems.

3. Outline of Simulation

In this study, we developed a simulation system which is called LoQAS; Locating services Quality Assessment System (2002, The University of Tokyo). The simulation system can calculate the distribution of the numbers of visible navigation satellites and DOP values of urban area using 3D digital map and accurate orbital information of navigation satellites. If there is the position or orbital data given, this system can be easily applied to new satellites such as Galileo or Quasi-Zenith Satellites

1) Numbers of Visible Satellites and DOP Values

LoQAS consists of 3D digital map of urban area and accurate orbital information of navigation satellites. The concept of direct signal simulation is shown in figure 1.

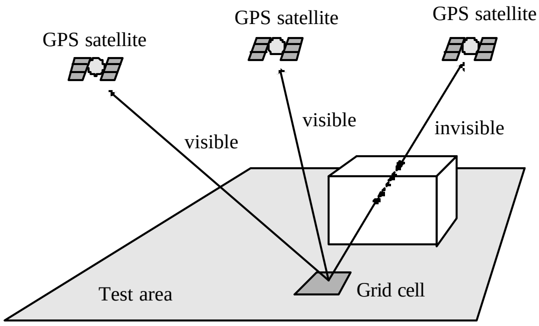


Fig. 1. concept of direct signal simulation of LoQAS

On the calculation of direct signal simulation, LoQAS divides test area into grid cells and checks if there is anything (usually it is building) blocking the line of sight from the center of a cell to a navigation satellite.

If there is one or more intersection points, the satellite is regarded as an invisible one. Checking all the satellites, we can know the number of visible navigation satellites for the grid cell. Repeating this calculation for all the grid cells, we can obtain figure 2. In this case, Test area is Shinjuku skyscraper area in Tokyo, and test date assumed is assumed to be 1st August 2002.

And using the information on visible satellites and their geometric distributions, we can calculate DOP values. Figure 3. shows the result. In this case, both the numbers of satellites and DOP values changes temporally because of the movement of navigation satellites. But piling snap-shot results many times with a short time interval, we can animate results which shows the results change through the time.

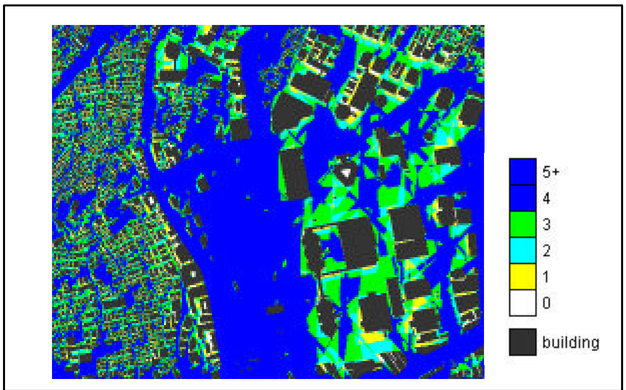


Fig. 2. numbers of visible satellites (Shinjuku area, Tokyo, 1st Oct. 2002)

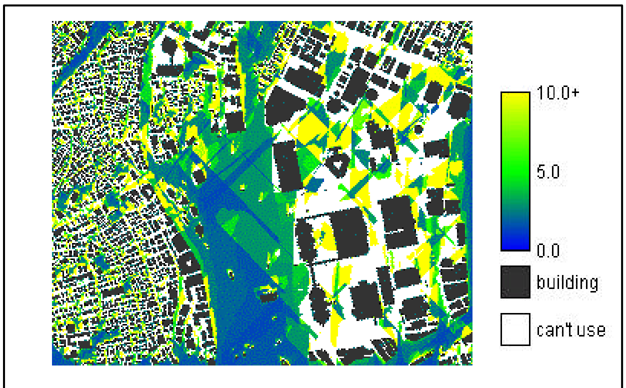


Fig. 3. Horizontal DOP values (Shinjuku area, Tokyo, 1st Aug. 2002)

2) Projection on Sky Views

Results of satellite visibility simulation of a specific location can be shown by sky view projection (Figure 4.). The test area is also Shinjuku area, and target satellites are GPS satellites and Quasi-Zenith satellites planned by Japan.

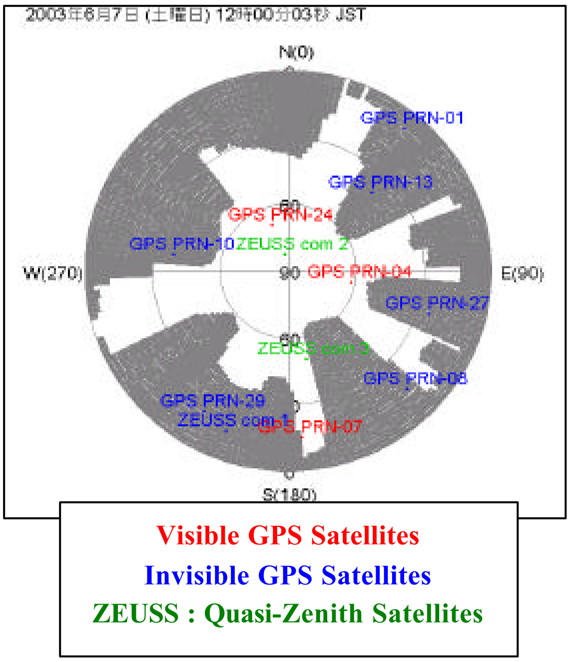
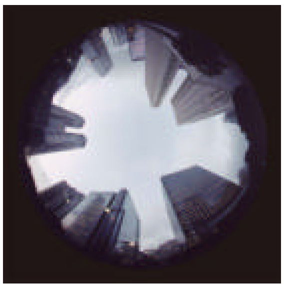


Fig. 4. sky view projection from the bottom of valley of buildings of Shinjuku area



fish eye photograph at the ground

Simulated building mask by LoQAS

overlaid image

Fig. 5. photograph with fish eye lens and projection by LoQAS

Comparing this projection with real photograph with fish eye lens which has sight of 180 degree, we evaluated 3D digital map LoQAS uses. To compare area ratio, we selected equisolidangle projection method. This projection method projects a object in same scale no matter it is on the center of the image or edge of the image. We computed the ratio of visible sky area to whole sky area of fish-eye image and the simulated image. That of real photograph was 39.3%, while that of LoQAS was 38.4%. Here we can say that the error is limited up to about 1%.

3) Evaluation of Simulation of the Number of Visible Satellites

To validate the accuracy of direct signal simulation, we conducted as experiment on 1^{st} Aug. 2003. Figure 6. shows the relationship between visibility simulation by LoQAS and observed SNR, both are of the GPS satellites (PRN No.05) in Shinjuku area.

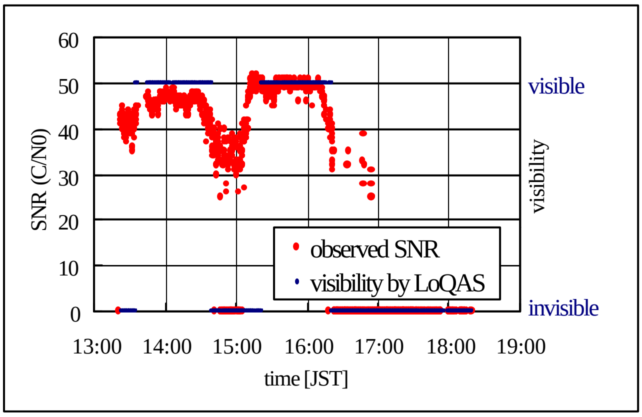


Fig. 6. relationship between SNR observed by GPS receiver and visibility estimated by LoQAS

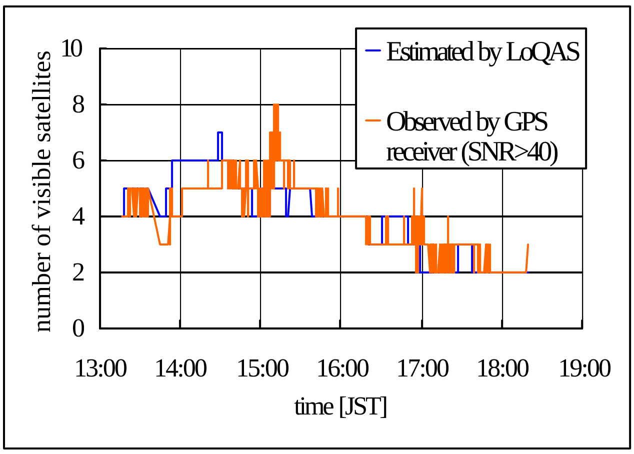


Fig. 7. Number of visible GPS satellites

Regarding the satellites of which signal's SNR is more than 40 as visible, figure 7 shows the relationship between the real number of visible satellites and that simulated by LoQAS. Here, average error was 0.11 and standard deviation was 0.83. It could be conducted that direct signals simulation by LoQAS is enough reliable including about 1 satellite error, though quality requirement of LoQAS have to be discussed further taking actual applications into account.

4) Simulation of Signal Reflection

So far, we simulated only signals which reach a receiver along the line-of-sight with LoQAS. The simulation of reflected signal using 3D digital map and orbital information of navigation satellites can be realized by introducing a ray tracing technique. Here, the scale of buildings are sufficiently big (more than 20 times bigger than wave length of GPS), so that LoQAS can deal with signal as a ray ignoring diffraction. And reflection makes the signal power so weak and more than 10 dBm of signal power is lost in one reflection according to our experiment. Signals which reflected more than twice can be disregarded. Therefore, LoQAS takes into account only specular reflection and single reflection of the signal for simplification. In other words, LoQAS traces the signals from navigation satellites until the first reflection and stops tracing if the reflected ray reaches any other surfaces. Figure 8. is the brief concept of this simulation. In this case, there is one direct signal and two reflected signals.

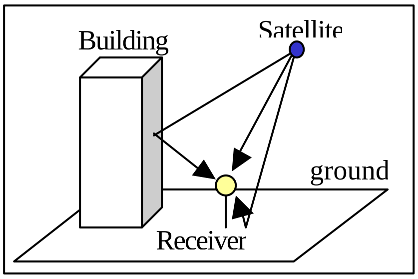


Fig.8. concept of simulation of reflected signal

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