Development of a Simulation System to Delineate Availability of GNSS with3-D Digital Map

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ABSTRACT

A Global Navigation Satellite System (GNSS) can be used as an effectual system for many applications that require fast and precise positioning. However, there are situations where GNSS fails to achieve the desired accuracy, for example when satellite signals are blocked or when the achievable accuracy is restricted by the layout of the satellite constellation. Therefore, a simulation system has been developed to assess the feasibility of GNSS in urban areas.

This paper describes about the simulation system which can calculate the number of visible satellites, Dilution Of Precision (DOP) and the error distribution using precise orbital information of the satellite and 3-Dimensional digital map. Furthermore, the simulation system may be applicable when installing new positioning satellites system like Galileo and ground-based systems (e.g. Pseudolites).

1. INTRODUCTION

1.1 Background

Because of the high precision of the carrier phase observable, the Global Navigation Satellite System (GNSS) technology has been widely used in real time monitoring crucial motion and ground subsidence, and more recently for deformation monitoring of man-made structures such as bridges, dams, buildings, etc. It is well known that, for such satellite-based deformation monitoring systems, the accuracy, availability and reliability of the GPS-derived position solution is highly dependent on the number of tracked satellites. However, in some situations, such in an urban, foliated, or mountainous environment, the number of visible satellites may not be sufficient to reliably determine position precisely. Furthermore, due to the limitations of satellite geometry, the accuracy of the height component is generally 2 or 3 times worse than the horizontal components [1]. These factors constrain precise GPS applications, making it difficult to make positioning applications successful in areas where the number of visible satellites is

limited or satellite geometry is very poor.

1.2 Objective

The objective of this research is to develop simulation system, which can calculate the number of visible satellites, Dilution Of Precision (DOP) and the error distribution using precise orbital information of the satellite and 3-Dimensional digital map. This paper describes about the principle and the concept of developed simulation system. Furthermore, the simulation system can be applied when installing new positioning satellites system like Galileo and ground-based systems (e.g. Pseudolites).

2. PRINCIPLE OF SIMULATION

This system consists of a 3-D digital map and a model of GPS satellites. The positions of GPS satellites are calculated using satellites' orbit information. The test area is divided into grid cells, where available areas of positioning, number of visible satellites and Dilution Of Precision (DOP) are computed. That is, if there is nothing to intersect the line of sight (LOS) from center of each cell to a GPS satellite, the satellite is regarded as available for positioning. By repeating this computation for individual grid-cells, areas where satellite-based positioning services are available can be delineated. Figure 1 shows the concept of this system.

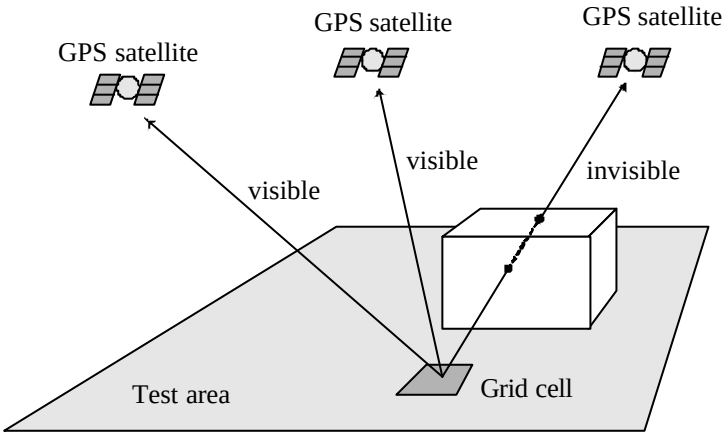


Figure 1. Concept of available of area estimation

In this simulation, DOP is calculated by equation below.

$$(G^T G)^{-1} = \begin{bmatrix} l_1 & l_2 & l_3 & \cdots & l_k \\ m_1 & m_2 & m_3 & \cdots & m_k \\ n_1 & n_2 & n_3 & \cdots & n_k \\ 1 & 1 & 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} l_1 & m_1 & n_1 & 1 \\ l_2 & m_2 & n_2 & 1 \\ l_3 & m_3 & n_3 & 1 \\ \cdots & \cdots & \cdots & \cdots \\ l_k & m_k & n_k & 1 \end{bmatrix}^{-1} = \begin{bmatrix} \sigma_{xx}^2 & \sigma_{xy}^2 & \sigma_{xz}^2 & \sigma_{xt}^2 \\ \sigma_{yx}^2 & \sigma_{yy}^2 & \sigma_{yz}^2 & \sigma_{yt}^2 \\ \sigma_{zx}^2 & \sigma_{zy}^2 & \sigma_{zz}^2 & \sigma_{zt}^2 \\ \sigma_{tx}^2 & \sigma_{ty}^2 & \sigma_{tz}^2 & \sigma_{tt}^2 \end{bmatrix}$$

Here, l, m, n are directional cosine (of the vector which has unit length and which is from the center of the cell to the satellite) for x, y, z direction, k is the number of the available satellites, and σ^2 is the

weight of the error probability for small letters directions. To estimate the error for the horizontal direction,

$$HDOP \; ? \; \sqrt{? \; {}^{2}_{xx} \; ? \; ? \; {}^{2}_{yy}}$$

and to estimate the error for the vertical direction,

$$VDOP \; ? \; \sqrt{? \; {}^{2}_{zz}}$$

are defined. The value of DOP changes not only by the change of number of the available satellites, but also by the change of their positions.

3. RESULT OF SIMULATION

Figure 2, 3, 4 show the results of the simulation which performed through the simulation. Using our system, we got results below. Test area is Shinjuku; a part of Tokyo. The condition of simulation time is set on Aug 1st, 2002. In this research, we only considered GPS satellites circumstance (even though this system can be easily adopted any other developing positioning systems too). Test area is divided into two meters mesh, we calculate available satellites' numbers, Dilution Of Precision (DOP). Figure 2 shows the numbers of the available satellites, and Figure 3 shows the area with the positioning service available.

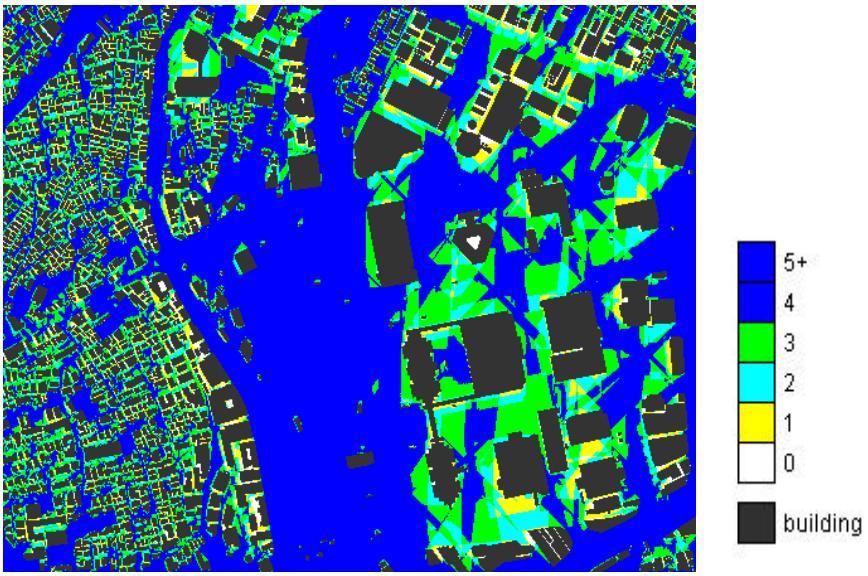


Figure 2. distribution of numbers of available satellites

Table 1. Ratio of number of available satellites

Number of available satellites	Ratio
More than 5	44.2 %
4	19.3 %
3	18.1 %
0 to 2	18.4 %

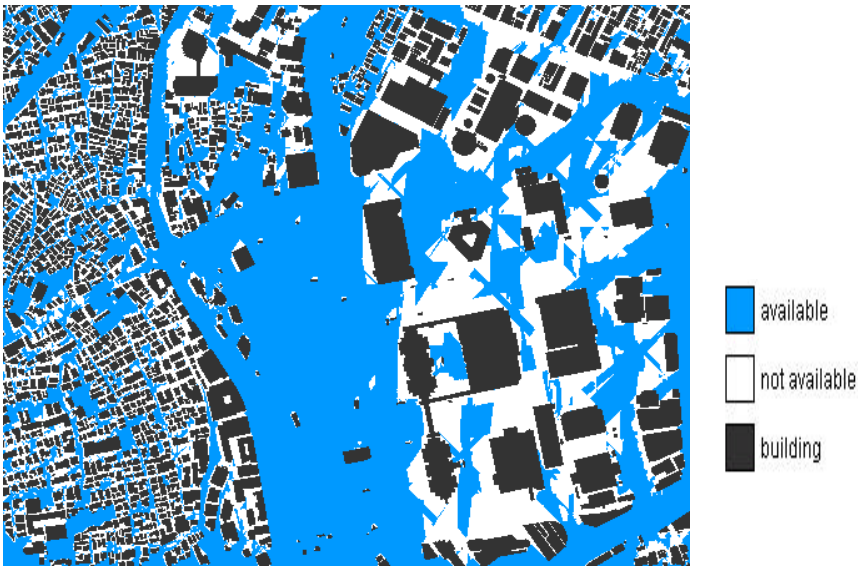


Figure3. Area with satellite positioning service available

Table2. Ratio of available area

Area	Ratio
In-service Area	63.5 %
Out-of-service Area	36.5 %

As is shown in figure 2 and figure 3, we can estimate distribution of number of visible GPS satellites and available area for positioning using GPS satellites. However, the number of available GPS satellites and available area change as time goes by. It is hard to say that which area is available for positioning or not in all day long even though the results of certain time show the availability. However, calculating distribution of availability through many computations with short intervals, it is possible to see the ratio of available area shown as in Figure 4. Interval time is 10 minute and total time is 24 hours. We calculate 145 steps to draw this figure. Using this system, we evaluate positioning system's efficiency independently on time.

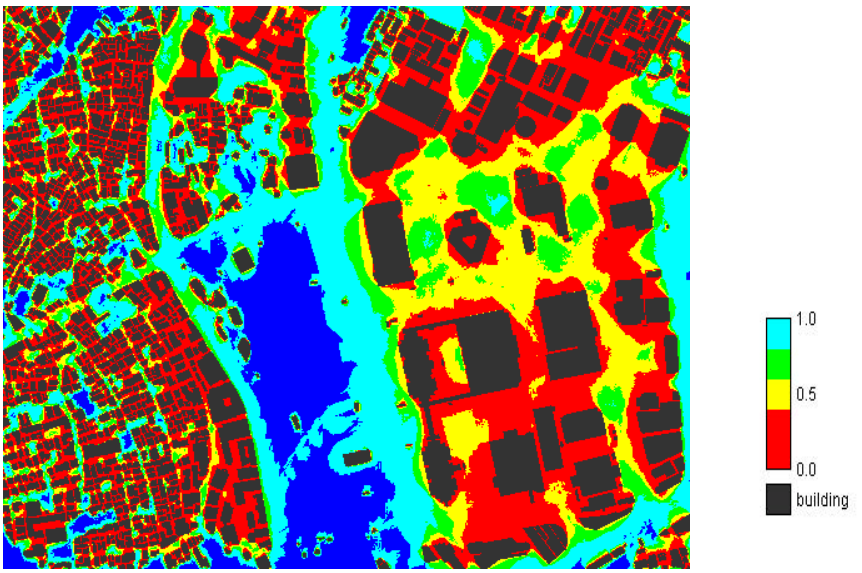


Figure4. Available time ratio par one day

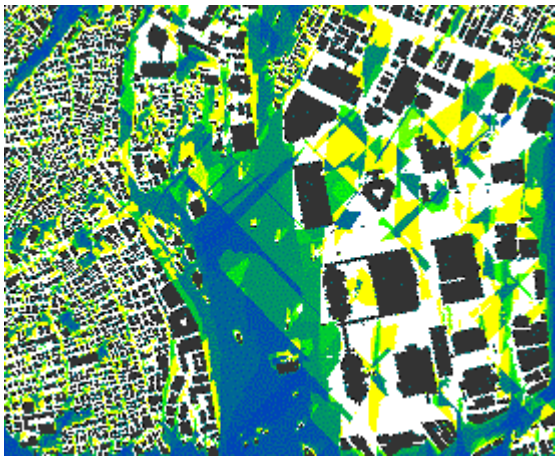
Table 3. Ratio of available time ratio

Available time ratio	Ratio
100 %	13.5 %
80 to 100 %	23.2 %
60 to 80 %	13.0 %
40 to 60 %	17.3 %
0 to 40 %	33.0 %

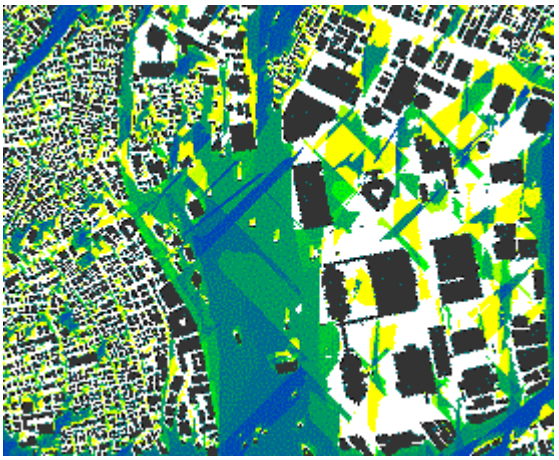
Shown in the above result, we know that it is impossible to use GPS receivers beside buildings because

the availability ratio of tracked GPS satellites may not be sufficient for accurate and reliable positioning.

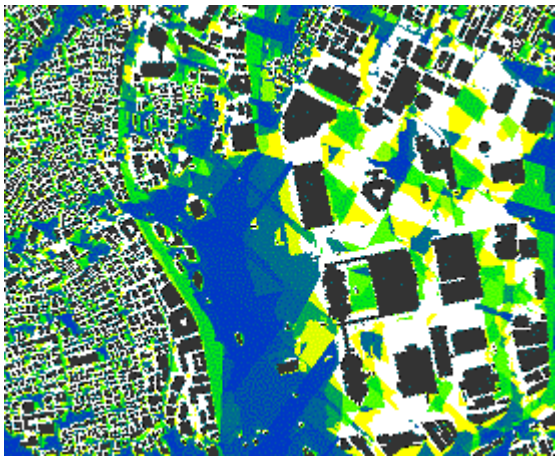
Figure 5 shows the HDOP and VDOP of the same time. As shown in these results, this system can estimate the distribution of DOP of any time. According to the results, value of VDOP at each time slices is worse than that of HDOP in the city part. This results match the actual circumstance.



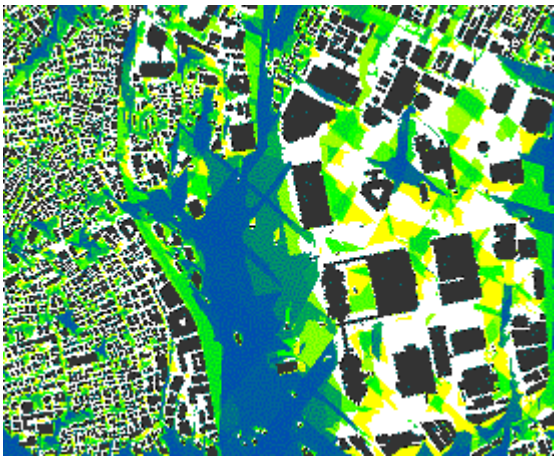
(a) HDOP (0:00 at Tokyo)



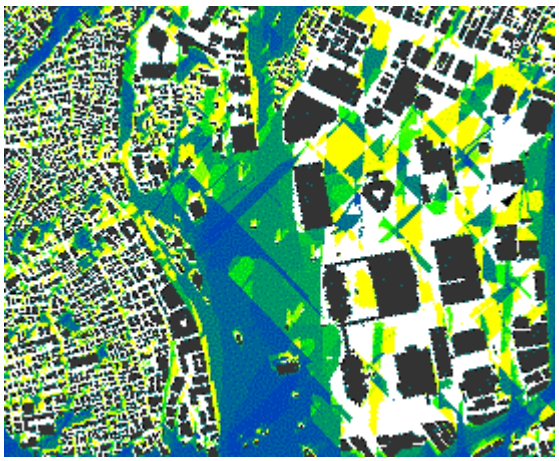
(b) VDOP (0:00 at Tokyo)



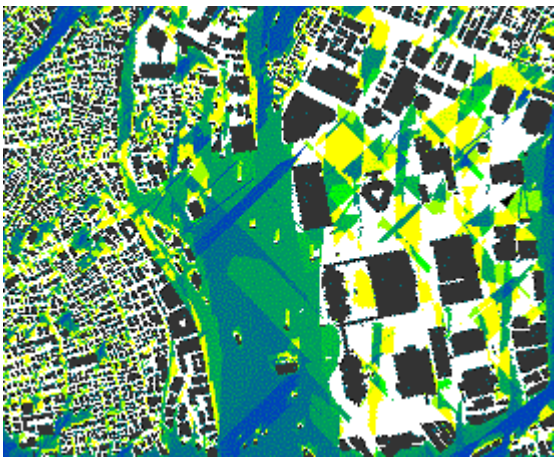
(c) HDOP (12:00 at Tokyo)



(d) VDOP (12:00 at Tokyo)



(e) HDOP (24:00 at Tokyo)



(f) VDOP (24:00 at Tokyo)

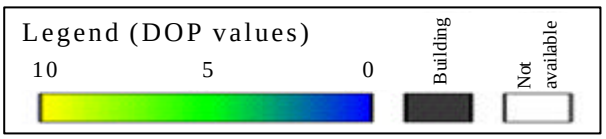


Figure5. Distribution of DOP

In each above figures, the color of white means unavailable area for positioning and it is impossible to using GPS satellite signals. It means just same as “not available” area of figure 3. In figure 5, there are a lot of areas where DOP has very high value; such as more than 10. In case of HDOP of an area is 10, we can assume UERE (User Equivalent Range Error: usually 25m) = 25m, the accuracy of that area is $10 ? 25 ? 250(m)$. It is worse accuracy for practical use.

4. CONCLUSIONS AND FUTURE WORKS

The purpose of this paper is to development system which can calculate the number of visible satellites, Dilution Of Precision (DOP) and the error distribution using precise orbital information of the satellite and 3-Dimensional digital map. Under the challenging conditions of urban environments the availability of GPS satellites could be verified through the developed simulation system. Moreover, this system will be applied when the new satellite-base positioning system is planed like Galileo and ground-based systems (e.g. Pseudolites) sufficiently.

As a future work, in order to evaluate the efficiency of this system, it is needed to compare the real experimental result of available area estimation and distribution of actual DOP.

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