Software-based Model of Urban Canyon Effect on GPS Signals Using 3D Map Data

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Abstract— In this paper, a software-based model of the urban canyon effect on Global Positioning System (GPS) signals is demonstrated. The proposed demonstration uses accurate three-dimensional (3D) model data from the real world in order to compare the conditions of urban and non-urban area. The positions of visible satellites were calculated and then utilized to determine which signals were blocked. The overall process was demonstrated using 2D and 3D results. Also, the process was further validated using experimental data retrieved from a u-blox receiver.

***Index Terms*—GPS urban canyon effect, 3D map data**

I. INTRODUCTION

The Global Positioning System (GPS) is a crucial component of the environment of modern transportation systems. As car navigators and map applications are more commonly used by individuals, the accuracy of positioning solutions provided by GPS has become increasingly important. Many studies have been performed to increase the accuracy and assure the integrity of GPS under various conditions [1]–[3].

At the same time, urban areas have become a difficult problem for GPS positioning because of their complex environments filled with high buildings. These concentrated building areas often cause the so-called urban canyon effect. The main effects of an urban canyon on GPS signals are shadowing and multipaths. Because GPS signals come from Medium Earth Orbit (MEO,) the strength of the signal is very weak and is easily blocked by a building. This effect is known as shadowing. Shadowing GPS signals worsens the geometric dilution of precision and the position estimation might not be trustable because the error is non-negligible. In addition, multipath signals can occur in an urban canyon. A multipath signal can affect to the result of positioning because multipaths cause inaccurate pseudorange measurements.

[1]–[3] show the effect of urban canyon environments and try to solve the accuracy problem. [1] describes the mathematical model of urban canyon environments and models the path of a vehicle, which is constrained to the road so that error is reduced to the position on the road. [2] utilizes an inertial navigation sensor along with GPS sensors to integrate extra information that is not affected by the urban environment. In [3], an omnidirectional infrared (IR) camera was utilized to compensate for the multipath signal. The IR camera tracks the position of visible satellites and excludes signals from “invisible satellites” because these signals must be multipath signals.

However, as far as our research group knows, no such research using three-dimensional (3D) map data has yet been done. With accurate 3D map data, it is possible to analyze the urban canyon effect more intuitively. Therefore, in this paper, a software-based model of the urban canyon effect on GPS signals using accurate 3D map data is demonstrated. This 3D map data includes not only the terrain data but also sophisticated 3D building models.

Section II of this paper describes the method of building the 3D model using VWorld data. Section III presents the detection of the urban canyon effect. In Section IV, the validation using experimental data is presented. Finally, Section V concludes the paper.

II. BUILDING A 3D MODEL OF A LOCAL AREA

In this study, terrain and 3D building model data from VWorld [4] were utilized to construct the ground truth of height data for a local area. VWorld is an open platform that provides accurate 3D map data including terrain data and building models. The data of VWorld is managed by the Korean government and updated using multiple high-accuracy sensors. Therefore, the 3D model of a local area based on the data from VWorld is considered to be ground truth in this paper.

The overall building process of 3D local area model is shown in Fig. 1.

A. Tiles in VWorld

VWorld provides its data as tiles of a map. Each tile is specified by its 2D coordinates and level. The top level, level 0, consists of 50 tiles. A level-0 tile is 36° wide in both longitude and latitude. The origin of the coordinates is at 90 °S 180 °W. North corresponds to the direction of the x-axis and east corresponds to the y-axis. The level is the division number for the top-level tile, so one tile of the previous level consists of four tiles of the next level.

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B. Building the 3D Terrain Model

Raw terrain data from VWorld is a binary string that consists of 4,225 height values in the requested tile. These 4,225 numbers form a 65 × 65 matrix that represents the terrain of the tile.

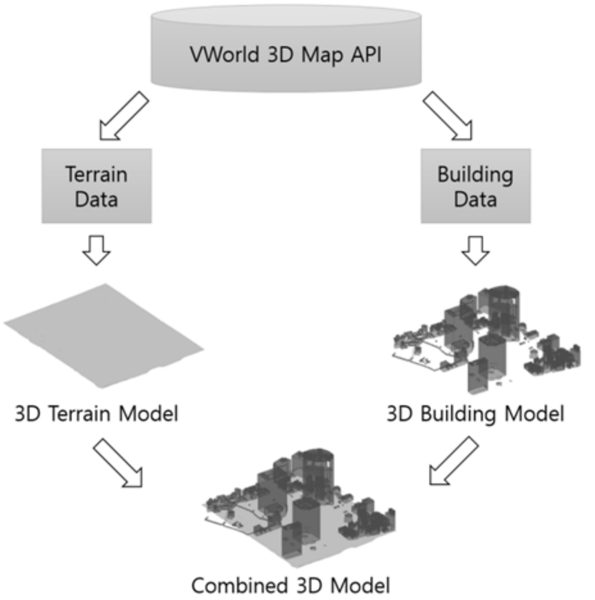

Fig. 1 Overall process for building the 3D model of a local area

C. Building 3D Building Model

Constructing a building model is more complicated than building a terrain model. At first, a request is send to the VWorld database to obtain a list of buildings within the designated tile. After retrieving the list, requests for each building in the list are sent again to download all building data files. Building location information and vertex data are then saved in the building data file. The vertex data is a set of vectors that indicates the location of polygons for the 3D building models.

D. Combining the terrain and building models

After building both the terrain model and building model, building components are aligned at the corresponding locations by the coordinates from the building data file. This process is repeated for all tiles. The tiles are then stitched together to create a 3D model of the local area.

III. Detection of the Urban Canyon Effect

A. Calculation of Visible Satellite Positions

The information of a visible satellite at a certain location is very important for the analysis of the urban canyon effect. As mentioned in the introduction of this paper, the two main elements of the urban canyon effect are shadowing and multipaths. Because the multipath effect is difficult to detect, the objective of the demonstration in this paper is focused on detecting the shadowing effect only, which can be detected with little effort. If a satellite is occluded by nearby buildings and the signal from that satellite is not received, shadowing has occurred.

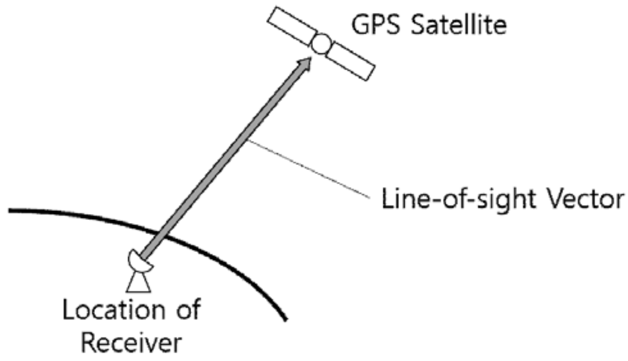

Fig. 2 Line-of-sight vector of a GPS satellite

Because a GPS satellite travels around the earth in an orbit, the location of satellites can be predicted if the properties of the orbit are known. The orbit information of a GPS satellite is contained within the navigation message of the GPS signal, thus the location of each satellite in Earth-Centered, Earth-Fixed (ECEF) coordinates can be calculated. The *a priori* ephemeris data from GNSS Data Center (GDC) [5] was utilized in this paper. GDC provides daily ephemeris data, so the closest one to the time of the positioning measurement was selected to calculate the satellite locations.

The visibility of a satellite is determined by the elevation angle. With the ephemeris data, each and every location of the satellites can be calculated, but some of them are not visible because the earth blocks the line of sight. Thus, the invisible satellites are excluded by selecting only satellites that have a positive elevation angle.

B. Determination of Shadowed Satellites

To determine whether the signal from a certain satellite is shadowed, each visible satellite is checked. This process examines if the line of sight from the current receiver's location passes through any nearby buildings.

IV. EXPERIMENTAL VALIDATION

A. Experimental Setup

In order to compare the received signal and visible satellite condition, experimental data is required. Thus, in this paper, a u-blox EVK-M8T [6] was used.

Fig. 3 u-blox EVK-M8 series [6]

The experiment was performed in July 2016 at Jonggak Station located in Seoul, Korea. The data was gathered at a fixed location for 801 seconds.

B. Demonstration Results

Figs. 4 and 5 show the 2D and 3D results of the proposed demonstration with the visualization of visible satellites. The 801th epoch of the experimental data is utilized in these results. The converging point of the lines of sight is the position estimated using the u-blox receiver. The results are represented in East North Up (ENU) coordinates, where the local origin is the estimated position. The number located at the end of each line is the Satellite Vehicle Number (SVN) of the GPS satellites.

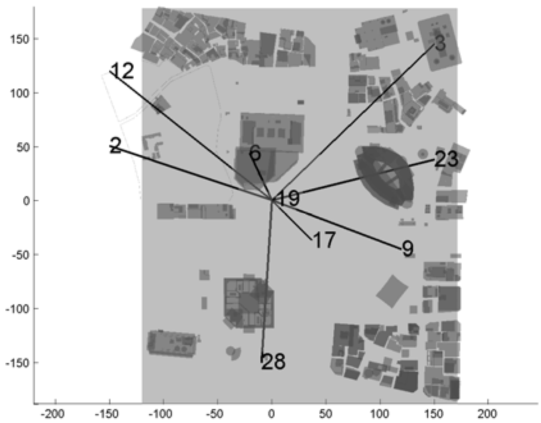

Fig. 4 2D top-view result of the demonstration

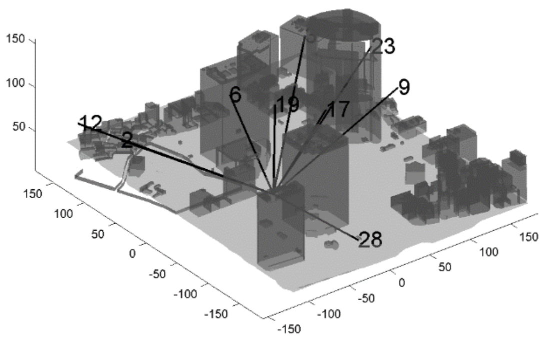

Fig. 5 3D perspective result of the demonstration

As shown in Fig. 4, there are several lines that penetrate nearby buildings, so the penetration section is not visible in the top-view result. The SVNs of these lines are 3, 23, and 28. The rest of the signal, which comes from SVNs 2, 6, 9, 12, 17, and 19 are received by the u-blox receiver. Therefore, the demonstration software correctly shows how the shadowing effect in an urban canyon would occur.

V. Conclusion

In this paper, a software-based model of the urban canyon effect on GPS signals was demonstrated. The data retrieved from VWorld was utilized to build an accurate 3D map for the area of interest. Based on this 3D map, the urban canyon effect is detected using the line-of-sight vectors of visible satellites and estimated positions. The locations of the satellites are calculated from the ephemeris data and lines of sight were constructed for each visible satellite that has a positive elevation angle. These lines of sight were utilized on the 3D map to examine whether the line passed through any nearby buildings. After the blocked satellites were found, the effect of urban the canyon was detected intuitively by the experimental positioning results. This demonstration was validated using real data retrieved from a u-blox receiver.

The model demonstrated in this paper an intuitive way to analyze the urban canyon effect of GPS signals and will be useful for further research purposes.

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