Visibility analysis and DEM uncertainty propagation

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Abstract

This study focuses on the problem of determining the accuracy of the calculated visibility analysis of an iconic building at Montevideo city, the Telecommunication Tower. This 157 m tall building is a very important architectural piece and also a central telecommunication tower. These two aspects must be considered in a visibility analysis: a) the building is expected to take a central role in the urban landscape, on the sightline of a significant part of the city; and b) the transmission scope of the tower must reach as many other telecommunication antennas as possible. The first matter can be considered as a sightline issue that requires calculating unobstructed line-of-sight between two points. The second one requires calculating Fresnel zone clearance to analyze interference by obstacles near the path of the electric radio-wave. In any case, the minimum height for the building is a function of the DEM of the city, conditioned to its expected visibility area. The study focuses particularly on the problem of determining the accuracy of the visibility analysis, by studying the propagation of DEM uncertainty.

Keywords: DEM uncertainty, visibility analysis, Monte Carlo, variogram.

1. Introduction

Visibility analysis is a common GIS problem that identifies visible areas from a specified observation point (Riggs & Dean, 2007), and It has a wide variety of applications in technical, environmental and social aspects that include civil-engineering, navigation, determination of line-of-sight relay networks for microwave communications (Nagy, 1994), visual impact analysis (Llobera, 2003), location of fire towers observation in forests (Akbulak &. Özdemir, 2008) and other intervisibility studies.

Most GIS software provides tools for visibility analysis. This functionality usually takes a DEM and applies standard functions that create boolean viewshed maps. The DEM is used in a deterministic way and possible inaccuracies and its impact on the final results are often ignored (Nackaerts *et al.*, 1999).

During a DEM's construction procedure there are several possible sources of errors, like the caused by projection conversions or image distortions occurred in the scanning process or imprecision related with resolution of the raster, etc. that affect its accuracy (Nackaerts *et al.*, 1999). The DEM resolution also affects its derived products (Hebeler & Purves 2007), as watershed delineation, terrain roughness, topographic indices and boolean viewshed maps.

One way to enhance the robustness of the analysis is reducing the uncertainty by using probabilistic error propagation analysis (Ukkonen *et al.*, 2011). Monte Carlo

simulation of a spatially autocorrelated error model is the most widely used technique for error propagation modeling (Zandbergen, 2011).

Despite the building has been erected in 2007 and there is no known plan to modify it, as an academic exercise we want to evaluate the effect of adding one more floor to the building, measuring the expected visibility area increase. The task, based upon a Monte Carlo approach, consists in create a large number of conditioned simulations of the DEM, calculate the viewshed from the observation point to each DEM's realization for the different tower heights, and process the collection of viewshed maps to estimate the viewshed spatial probability function.

1.1. DEM and uncertainty

A Digital Terrain Model (DTM) is a numeric data structure that represents the spatial distribution of a continuous quantitative variable (Felicísimo, 1997). If the represented variable is the terrain´s ground elevation in relation to a specified reference system then it is called Digital Elevation Model (DEM). If the represented variable is the top of trees and/or building roof it is called a Digital Surface Model (DSM). Both DEM/DSM are useful to 3D representation of the earth surface based on its altitude values (altimetry and bathymetry).

During a DEM elaboration process there is an implicit or explicit schema to interpolate the measured values in order to obtain a continuous and differentiable surface in which the values of elevation, slope and curvature can be estimated at any point. The uncertainty associated with the applied interpolation procedure affects the model, so the DEM itself will have some uncertainty and DEM's derived products, such as visibility analysis, will be affected by an uncertainty propagation effect.

A model uncertainty analysis aims to provide quantitative measures of final values uncertainty due to uncertainties in the model itself and the input values. It is helpful to examine the relative importance of these factors and report their results. Knowing its uncertainty level may be considered as an improvement in the derived product quality.

Uncertainty analyses are usually performed through a probabilistic study of error propagation, using statistical simulation techniques such as Monte Carlo simulation of a spatially correlated error model.

1.2. Simulation, Kriging and Variogram

In geostatistics, simulation is the realization of a random function that has the same statistical features (same probability spatial distribution, described by the variogram) as the sample data used to generate it. The studied phenomenon is described by a set of correlated random variables. Multiple, equally likely representations of the spatial distribution of the attribute under study can be generated. These representations provide a way to estimate uncertainty for the unsampled locations (Samper and Carrera, 1990).

Variogram is a statistical property of the field that characterizes the spatial correlation at different distances. With just the variogram we can produce what is known as Unconditional simulation. On the contrary, a Conditional simulation honors field data values by forcing a set of simulated values to match them for every realization. An Unconditional simulation field can be transformed to a Conditional one by Kriging.

Kriging is a method to estimate spatially dependent fields and their variance

based on a number of known observations and a variogram. A kriging estimator provides an optimal estimate value in relation with the minimum mean-square-error that produces a smoothed reality. It also determines an estimation of the error variance, a kriging variance, which quantifies the uncertainty of an estimate at each location.

2. Methodology

The proposed DEM uncertainty analysis to determine viewsheds required the following steps:
1) Estimate the variogram of the error field for the DEM using independent elevation data.
2) Perform several conditioned simulations to produce a large number of equally likely DEM realizations.
3) Calculate the viewshed from the observation point to each DEM's realization
4) Process the collection of viewshed maps to obtain the distribution of possible correct visibility analysis.

The software used in all processes: Octave, EasyDem, SgSim, gvSIG and Sextante.

2.1. Variogram

The difference of elevations between the DEM and ground truth from a geodetic leveling campaign has been calculated for 135 locations, evenly distributed in the domain. The error field is assumed to be isotropic, hence the correlation between the data does not depend on the direction in which it is calculated (Samper and Carrera, 1990).

The optimal variogram estimated by EasyDem software for the spherical theoretical model has a sill = 110.84 m^2 and range = 11937 m.

2.2. Simulations

The simulations were performed by Sequential Gaussian Method (SGM) using the SgSim toolbox (Hansen, 2004) and based on a DEM of Montevideo surface. In a real application a DSM should be used instead. However, an urban DSM usually does not satisfy the assumptions needed for kriging simulation; the simulation should be carried out for the DEM and later a deterministic (DSM-DEM) blanket should be added on top of the simulated DEM. In our case we do not have the necessary building's height information, so we just used the bare ground data. DEM data is available as a one-band TIFF raster with 86 meter spatial resolution, georeferenced in UTM 21S coordinate system.

To optimize the computing time the original 405x309 raster was subsampled at 1/9 pixel, obtaining a 145x103 raster with nearly 256 meter spatial resolution.

2.3. Viewshed calculations

The visual basin associated with a specific cell is determined by its set of visually related cells, and it is usually represented by a boolean viewshed map.

The tower is located at X=573562, Y=6138642 coordinates, and is 157 meters high. A viewshed calculation from this point was made for each one of the DEM simulations using the Sextante visibility algorithm (Olaya, 2012) through gvSIG

software, obtaining 120 different and equally possible visibility basins for the tower. We derive from them a probability map, an average viewshed and an histogram of total visible area. The calculations were carried out in Octave.

The same procedure was carried out considering two hypotheses about the tower's height: 1) one more floor is added so the tower height is 162 meters high, 2) the maximum height set up by the Urban Planning Law's is considered and the tower is 75 meters high.

2.4. Results

The viewshed probability maps for 157 and 162 high meters are very similar with almost no difference between them (Figure 1). The same applies respect to the visibility areas, reported in (Table 1). The histogram in both cases shows that only a few pixel changes from *not visible* to *visible* category and being most part of pixels always visible (Figure 2).
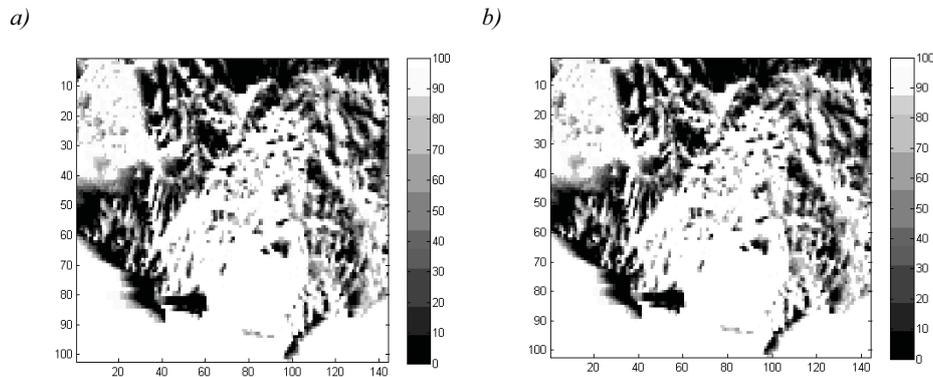
a) *b)*

Figure 1: Viewshed probability map for: *a)* 157 meters height and *b)* 162 meters height.

Table 1: Comparative results of calculations performed with different tower heights.

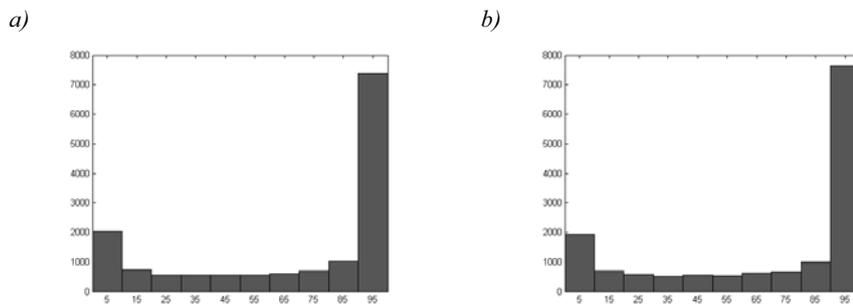| Height	Visibility area in km^2				
	Min	Max	Range	Mean	Std. Deviation
75 m	281	421	139	353	27.3
157 m	622	707	85	664	16.7
162 m	637	719	81	676	15.9

a) *b)*

Figure 2: Probability histogram for: *a)* 157 meters height and *b)* 162 meters height.

Important changes are noticed when comparing with the 75 m. results (Figure 3);
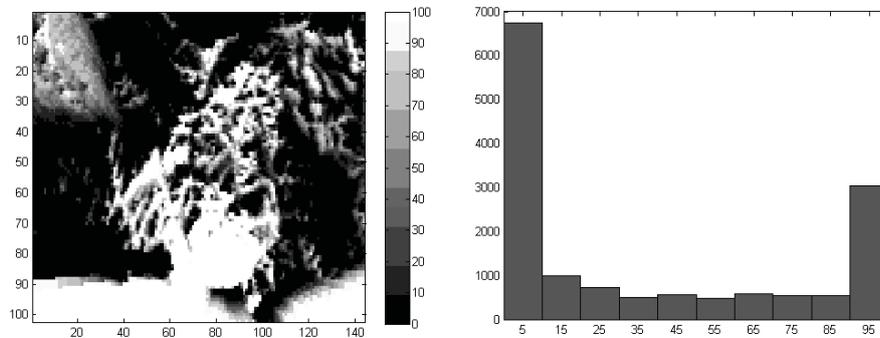the visibility area reduces drastically.

Figure 3: Probability map and histogram for 75 meters height.

The tower at its actual height (157 m) really rises on the sightline of the most
part of the city. Increasing the height about 5 more meters does not bring substan-
tive changes, and the visibility area only increases 1.8%.

It is also important to notice that increasing the height from 75 to 157 meters,
strongly impacts the visibility area, increasing it by 88%. So if the regular urban
planning rules were strictly applied, the visibility area would be much lower.

3. Conclusion

Based on the results it is possible to conclude that the proposed methodology is
appropriate to perform DEM based calculations to obtain derived products manag-
ing uncertainty in the original elevation data.

The same methodology could be applied if elevation data refers to an urban
building surface (obtained by LIDAR technology for instance), or if the maximum
height admitted by Urban Planning Law's is considered. A sufficient number of
simulations are required. The process requires not large computing resources, so its
practical application at the design stage is in fact possible.

In this analysis the DEM is the single source affecting the expected visibility
area, because the height of the city buildings were not available. This study is an
academic exercise for a recently built tower, but for a real analysis we should cal-
culate intervisibility over DSM instead of DEM, considering the building's top
surface in order to obtain more realistic results.

The result of visibility analysis showed that the tower current height is signifi-
cant enough for the used DEM elevation data and no serious changes in visibility
are noticed when adding a 5 more meters height floor. It also demonstrates that it is
not possible to follow general height's city regulations and at the same time achieve
a viewshed area as relevant as it is at the present.

This study focuses on the visibility analysis, but the methodology is also appro-
priate to manage the DEM uncertainty if calculating Fresnel zone to electric radio-
wave transmission (main goal of the tower).

Future work will check predicted visibility by the model with field observations
acquired data to compare the calculated results against reality.

Acknowledgments

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