Modeling and Validation of Elevation Data Obtained by GNSS and Drone Devices for Managing Floodings in Coastal Lands Caused by Climate Change

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Abstract. *This short-paper reports and explores a methodology to model and validate geographical elevation information from samples, points and images, acquired by Global Network Satellite System (GNSS) and Aerial Drone devices. The elevation models will be used on flooding management activities of coastal lands caused by climate change. The methodology of this article addresses details: on how to obtain and process GNSS sample points and drone images to generate the final Digital Elevation Model (DEM) and; on how to validate the DEM information to attain its quantitative quality. Also, the article presents some initial ideas for creating different flooding scenarios according to the sea level variation. The simulated scenarios can be used on decision making activities to minimize risks of human and material losses. The up-to-now results, obtained in a case study in* ***Guaecá*** *beach area, show the applicability and the feasibility of the proposed methodology.*

1. Introduction

Climate change has pointed, according to the consensus of many serious researchers, to an increase in the planet's temperature [Hansen et al. 2006, Menne et al. 2018]. One of the effects mentioned is the possible rise in sea level that can cause, among other problems, floods in coastal areas, notably in urban areas [Brown et al. 2020, Frederikse et al. 2020, Hinkel et al. 2019] [Brow et al. 2020, Frederikse et al. 2020, Hinkel et al. 2019]. The delimitation of the area to be flooded is crucial for scenario simulations that indicate the loss of urban area with large population density and, usually, with high economic value. In Brazil, 60% of the population lives in the coastal range [Marengo and Scarabi 2016]. Significant effects also occur in non-urban coastal areas, such as those with coconut plantations, for example.

The scenarios' creation simulating increases in the current level of the oceans is essential for public managers to make preventive decisions to avoid these floods, or even mitigate their effects, as the economic, social and environmental damages can be quantified with the scenarios. The work of delimiting these flooded areas begins with the creation of a Digital Elevation Model (DEM), a relief representation, of the geographic region of interest. Thus, the DEM to be used to accomplish reliable simulation processes must be of the best possible cartographic quality considering the spatial position and, mainly, the elevation information. Shuttle Radar Topography Mission (SRTM) [Rodriguez et al. 2005] and ASTER Global Digital Elevation Model (GDEM)

[Abrams et al. 2020] are examples of DEMs that can be found for free in the internet. Unfortunately, for high quality simulations, those data are not suitable. DEMs of high spatial and altimetric accuracy can be created from a set of sample points obtained using GNSS instruments and/or a set of drone images [Sze et al. 2015, Bolkas et al. 2016].

In this context, the objective of this article is to report and to explore a methodology to model and validate elevation data addressing the topics of how to obtain and process GNSS sample points and drone images to generate a high accurate DEM and of how to validate the DEM information to assess its quantitative quality. Geostatistical and interferometry procedures are used to create the DEMs while direct and cross validations are considered to evaluate their global accuracies. A case study in the beach of Guaecá, located in the city of São Sebastião, on the northern coast of the State of São Paulo, Brazil, is used to illustrate the applicability of the proposed methodology. Also, results of the case study along with related discussion are presented.

2. Material and Methods

The input data in this research are a sample set of elevation points and a set of high-resolution images acquired in a geographical region of interest. The sample set was collected using Global Network Satellite System (GNSS) instruments while the images were acquired by drone flights carried during field works. The sample points were determined on-site through three GNSS geodetic equipment: Sokkia Stratus (L1 frequency), Topcom Hiper (L1/L2 frequency) and Trimble R-4 (L1/L2 frequency). The images were gathered on aerophotogrammetric surveys and conducted using a quadcopter multimotor UAV model Phantom 3 Advanced drone, equipped with a Sony Exmor sensor with 12.76 megapixels and focal distance of 3.61 mm.

The methodology of this research has the following steps: acquisition of a set of elevation points using GNSS equipment; gathering local images by drone flights; processing the GNSS raw data to obtain orthometric referenced information, hereafter named GNSS samples; processing the drone images, with the support of the GNSS samples, to obtain the drone models of the mapped region, the Surface DEM (SDEM) and the Terrain DEM (TDEM); creation of a DEM model using the GNSS samples, hereafter named GNSS DEM, and geostatistical tools known as variography analysis and kriging prediction and; validations of the GNSS and the Drone DEMs by means of direct and cross validation procedures. The methodology above was applied in a case study and the results are presented and analyzed in the next sections of this article.

The geometric heights of the raw GNSS data, were transformed into geoidal orthometric heights, based on the reference geocentric ellipsoid GRS80, in the software MAPGEO 2015 [Blitzkow et al. 2016]. The Drone DEMs were created using the PIX4D [Barbasiewicz et al. 2018] software. The PyESSDAES software [Felgueiras et al. 2019] was used to generate and validate de GNSS DEM. The Geographical Information System (GIS) SPRING [Câmara et al. 1996] was used as the spatial database for visualizations and complementary analyses of the GNSS sample set and the resulting DEM maps.

3. A Case Study

The proposed methodology was applied in the coastal region known as Guaecá beach located in the municipality of São Sebastião, on the northern coast of São Paulo state, Brazil. Figure 1 presents the Guaecá region, with latitudes from 23º 49' 00" S to 23º 49' 27" S and longitudes from 45º 27' 50" W to 45º 27' 09" W.

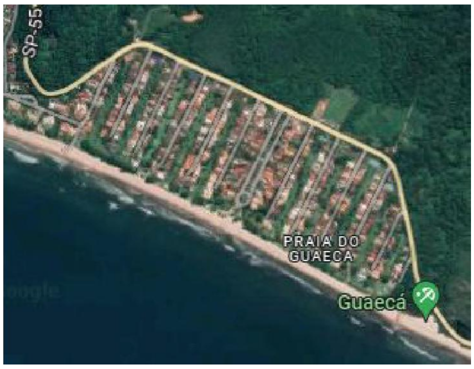


Figure 1. Guaecá region (Source: Google Maps)

Figure 2 shows the spatial distribution of points of the GNSS sample set, marked as plus signals, along with their elevation values, plotted in the SPRING software. Elevation statistical values of the 57 sample points are: minimum 1.03m, maximum 6.15m, mean 3.95, variance 1.70m, standard deviation 1.30m, coefficient of variation 0.33m, skewness -0.66m and kurtosis -0.15m. All the sample points coordinates, horizontal, vertical and altimetric, present accuracy better than 10cm.

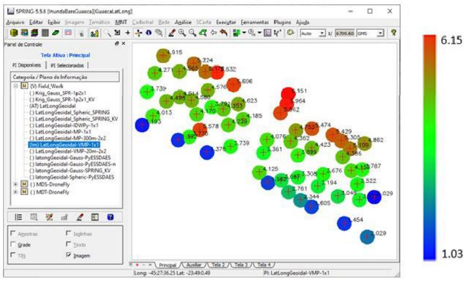


Figure 2. GNSS sample set of the Guaecá region

Figure 3 illustrates the drone image acquisition planning showing, in yellow lines, the programmed flight regions.

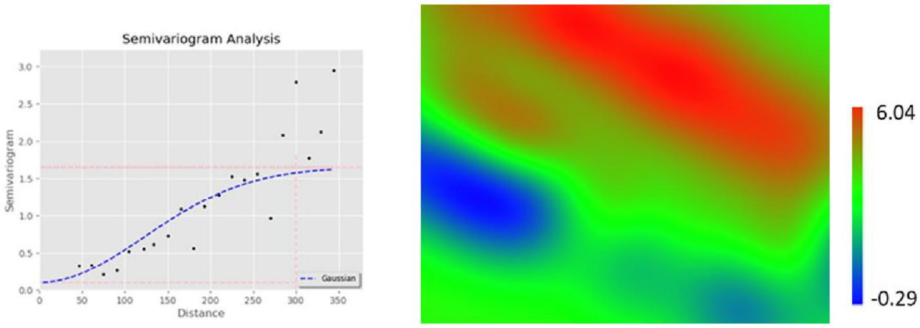
Figure 3. Drone flight areas in the Guaecá region

4. Results and Discussion

This section presents some results and discussion related to the modelling and validation of the DEMs created for the case study region considered in this article.

4.1. Digital Elevation Model from the GNSS sample set

Figure 4, shows results of the semivariogram analysis of the GNSS sample set and the predicted map, the GNSS DEM of the Guaecá region, obtained in the PyESSDAES. The theorical semivariogram of Figure 4(a) was fitted with a Gaussian function having 0.12m of nugget effect, 1.55m of contribution and 296.5m of range values. The map of Figure 4(b) was accomplished with the geostatistical estimator, known as ordinary kriging approach, creating a grid of 798 columns x 746 rows with a spatial resolution of 1m x 1m.



(a) (b)

Figure 4. The semivariogram of the GNSS sample st and (b) the DEM of Guaecá region

Visually, the general aspect of kriging estimated map agrees with the circle colors of the sample set presented in Figure 2. Also, the estimated map, as expected, presents a smooth surface representing the tendency of the elevation sample set information.

4.2. Digital Elevation Model from Drone Images

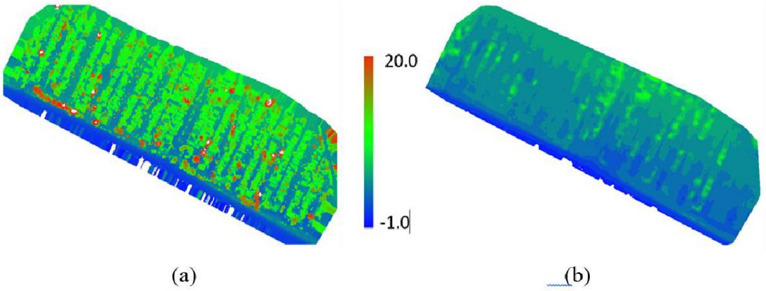
The resulting maps of the processed drone images are presented in Figure 5. The map of Figure 5(a) is the Surface model, hereafter named as Drone SDEM, while the map of Figure 5(b) is the Terrain model, hereafter named Drone TDEM. The SDEM contains extra terrain information, as edifications and vegetations, that were filtered, inside the Pix4D the software, to generate the TDEM information.

Although the Figure 5(a) presents more details, more red spots for example, it cannot be suitable to applications that require only the terrain information.

4.3. Direct and Cross Validations of the DEMs

The GNSS DEM and the Drone DEMs were validate using cross and direct validations to assess the quantitative quality of the generated elevation Models.

The cross validation was performed only for the kriged GNSS DEM. In this process, elevation values are predicted from GNSS DEMs not containing the sample in consideration. Differences among actual elevation and respective predict sample values are



(a) (b)

Figure 5. Drone Models of Guaecá region: (a) Surface Model (Drone SDEM) and (b) Terrain Model (Drone TDEM)

considered to obtain statistics and Root Mean Squared (RMS) error values of the differences. The GNSS sample set as the test data for the direct validations was used in this research. Although this is biased, because the same sample set was used to obtain the DEMs, this was the only source data available up to now for this task. In the near future a specific field work will be carried out to get independent test data for the validations.

Table 1 reports the results of the DEMs' validations using cross and direct validations for the kriged GNSS DEM and direct validations for the drone DEMs.

Table 1. DEM Validation results

		Statistics / Errors (m)			
		Mean	Variance	Std. Deviation	RMS
DEM	GNSS DEM Cross	-0.007	0.77	0.88	0.88
	GNSS DEM	0.19	0.34	0.58	0.61
	Drone SDEM	0.04	0.24	0.49	0.49
	Drone TDEM	-0.40	0.35	0.59	0.71

It can be seen by analyzing the results presented in Table 1 that quantitatively the Drone SDEM is the best model obtained in this study. This can be explained by the fact that it uses the Drone data besides the GNSS samples. Moreover the GNSS DEM represents only the tendency elevation and the Drone TDEM was derived from the application of a filter in the Drone SDEM data. Better results are expected when using the independent set of test samples that will have accuracy error lower than 10cm.

5. Final Remarks

This short paper presents and explores, with a case study, a methodology to model and validate elevation information from samples obtained with GNSS and Drone devices. The outcomes demonstrate the applicability and the feasibility of the proposed methodology. Also, the quantitative results of the DEMs' validations show that the use of drone information, along with GNSS basic data, increases the DEM accuracy.

This research is the first step of a more complex experiment that aims to use DEMs as basic input data for flooding management activities of coastal lands caused by climate change. The idea is to propose a complete methodology that allows to delimit flooding areas in coastal regions, mainly the urban ones, considering the sea level rising.

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