3D RECONSTRUCTION OF HILLS OF SANJAY GANDHI NATIONAL PARK REGION FROM DIGITAL RASTER ELEVATION DATA

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ABSTRACT:

Reconstruction and modeling of large geospatial features such as terrain and mountains are vital in study and planning of ecological infrastructure. This includes wild animal habitat, urban and civic planning. Identifying zone of influence of natural infrastructures such as forest, hills, and mountains has the valuable contribution. Wildlife safety and tracking activities can be better monitored and executed if visualization and simulation of the affected region are available. This paper presents a geostatistical approach for reconstructing and visualization of hills of the region around Sanjay Gandhi National Park, Borivali, India from raster data and identifies the zone of immediate influence of wildlife to adjacent urban regions. Reconstruction of 3D geospatial hills and mountains has been achieved from raster image data of 30m resolution obtained from satellite imagery. Contour list of the lower reach of wildlife over these mountains is identified, extracted, georeferenced and finally integrated together with the constructed 3D hills. Additionally, hydrological sources in the nearby area are also identified and saved for virtual modeling and visualization purpose. It is shown that bilinear and cubic convolution based interpolation is more suitable than nearest neighbor estimates for raster data of test region. The results are physically verified with known ground truth values and also validated with google maps in a georeferenced environment. The accuracy of around 97.13% has been obtained for the reconstructed hill region.

Keywords: 3D Reconstruction, Visualization, Geostatistical Modelling, Digital Elevation Model

[1] INTRODUCTION

Modeling and visualization of large natural features on the earth have interesting applications and can be achieved in many ways. These natural features include mountains and
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hills, terrain blocks, forest and hydrological regions. Terrain analysis and landform recognition [1] has emerged as an important area of reconstruction and visualization. Many of the wildlife conservation projects have been concentrated on forest hills and mountains. This requires developing knowledge about its geographical distribution to enable better planning purposes. This knowledge can be more useful if these geographical features can be visualized in the 3D interactive environment. This motivates the development and research for reconstructing 3D structures in the georeferenced environment. Among several types of data set used in reconstruction activities, popular ones include point clouds from LiDAR [2], [3] systems, photogrammetry [4] and raster data obtained from satellites. Raster data includes digital elevation models (DEMs) [5], ASCII grids and orthoimages describing geographical information that includes surface elevations.

Airborne LiDAR and photogrammetry based data competes each other for specific application but they have different approach. While point clouds have provided the opportunity for 3D reconstruction with a good level of details, it suffers for performance reasons due to the high level of complexity in processing large count of point data in them. Similarly, the second approach is the use of photogrammetry which requires multiple samples of images of the same object/feature and needs establishing correspondences before generating point clouds for mapping and texturing. The third approach is extracting 3D information contained in raster data such as satellite images. While the textural details of reconstructed features obtained from raster images are as good as those obtained from photogrammetry but it offers a simpler and efficient way for reconstruction of large features. This motivates to develop a framework for reconstructing 3D forest hills and mountains including foot-hills of the national park as the habitat of preserved wildlife. Approximating the zone of wild life reach for safety reasons is also realized and method for the same has to be developed.

[2] RELATED WORK

Reconstruction of natural and man-made objects have gained much attention due to its wide scope in emerging applications across domains. Reconstruction of heritage structures[6], forest areas [7] and terrain models are some prime areas of reconstruction and visualization research activities. Reconstruction and visualization of heritage structures and archaeological features can be easily achieved using LiDAR mapping [8], [9] and photogrammetry [10]. However, large landscapes including those involving forests and mountains are challenging due to large coverage area and requirement of survey and data gathering efforts. Airborne LiDAR is a good way to gather data about it. However it is not always cost effective due to acquisition setup and data processing efforts at later stages. Raster-based methods of reconstruction of the large natural geographical feature are the preferable method. Reconstruction of natural features such as terrain and mountain range has increasing interest of researchers

The study of 3D Terrain Visualization techniques [11], [12] suggests the usefulness of remote sensing and raster data such as DEMs in landscape modeling and terrain reconstruction [13]. Reconstruction attempts of mountain Taishan [14] and Polish Tatra Mountains [15] also exhibit the use of DEM (SRTM) and digitalized vector data for three-dimensional reconstruction. Software tools and libraries [16] with custom spatial processing pipeline can help in generating interesting results. Investigation reveals that reconstruction of mountain ranges with reference to wildlife habitat has limited attempts and need more focused work. This
paper attempts to develop a framework to reconstruct and model mountains of Sanjay Gandhi National Park region using raster images. It also assesses the physical proximities of wildlife influence at the foothills and nearby forest region based on distance criterion and dwelling possibilities.

[3] EXPERIMENTAL DATA

The experimental data set for validation and proof of concept is obtained from Shuttle Radar Topography Mission (SRTM GL1) Global 30m Ellipsoidal data set (OTSRTM.082016.4326.1). Horizontal and vertical coordinates are WGS 1984 [EPSG: 4326] and WGS84 respectively. The data coordinates are Xmin: 72.777557, Xmax: 73.00827, Ymin: 19.115327 and Ymax: 19.316327 respectively. The satellite view using google map is shown in Figure 1 and raster ASCII grid image is shown in Figure 2. The raster data used as input is either an ASCII data file or a GeoTiff file encompassing elevational values. The number of rows and columns are 831 and 724 respectively. The cell size of the sample files 0.00027777778. Being an elevational data format, DEMs store three coordinates for any location. The coordinates x and y denote horizontal position in the surface of the earth and z signify the elevational value at this location. The elevation values are extracted from each cell for reconstruction.

Figure 1: Satellite View of Test Region Using Google Map
[4] RECONSTRUCTION AND VISUALIZATION OF NATIONAL PARK MOUNTAINS REGION

This paper uses raster data acquired from the satellite over the Sanjay Gandhi National Park forest hill region. The raster surface from SRTM DEM data can be plotted using variety of software tool [16] and further processing it further for specific needs. Although the 3D view obtained by plotting layer based on elevational values gives the general arrangement of features but lacks in conveying concrete information about the specific geographical identity of features like mountains, trees, and rivers. The comparison of different techniques for visualizing 3D terrain data [17] suggest slope, contour, hill shade and kernel densities can be useful to achieve the objective of 3D reconstruction. The proposed framework for hill reconstruction and visualization of the test area is divided into stages as shown in Figure 3.

The structure of the earth reveals that it is not uniform but has variability in relief. Reliefs are generally expressed gradient [18] and help to examine the surface. The gradient can be used to describe the change in the vertical versus horizontal dimensions. Simply computing horizontal area changes is not useful especially in mountain reliefs and hence less relevant in 3D reconstruction and visualization. Steep sloping as seen in mountain terrains have to be modeled in correspondence to its physical space. Hence to determine the hills of national park region and computer wildlife influence zone; features like slope, aspect, contour lines and hill shade is computed and then augmented with the reconstructed model for the final result A brief description of the proposed framework and related concept used for experimental work is discussed next.
TABLE I: Performance Characteristics of Interpolation on 3D Visualization

<table>
<thead>
<tr>
<th>Interpolation Technique</th>
<th>Nearest Neighbor</th>
<th>Bilinear Interpolation</th>
<th>Cubic Convolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Output depends on nearest cell center on the input grid.</td>
<td>Weighted average of the four nearest cell centers.</td>
<td>Uses 16 nearest cell centers to produce the output</td>
</tr>
<tr>
<td>Type of data</td>
<td>Categorical data</td>
<td>Continuous data</td>
<td>Continuous data</td>
</tr>
<tr>
<td>Applications</td>
<td>Useful for land-use classification or slope classification</td>
<td>Useful for elevation and raw slope values output value could be different than the nearest input</td>
<td>Changes values of input and also sometimes result in values outside the range</td>
</tr>
<tr>
<td></td>
<td>Use on continuous data results in block appearance.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A. Extract Elevation and Generate 3D terrain Structure

To construct and visualize 3D view from the raster, the elevational value in raster data at each position in the raster is used. A 3D view is constructed by creating layers of elevations/height (z) information contained in the raster. It may be noted that the elevational layers provide a 3D definition for other layers to place on them. The elevational data is then used to obtain the digital terrain model (DTM) and rendered using software tools like QGIS or ArcScene. For visual perception, interpolation techniques like the nearest neighbor assignment, bilinear, and cubic convolution are applied. Table I describes the characteristics of these interpolation techniques.

Bilinear and cubic convolution based interpolation give better results. The dimensions of the resulting raster is calculated as follows

\[ N_c = \frac{x_{\text{max}} - x_{\text{min}}}{C}, \quad N_y = \frac{y_{\text{max}} - y_{\text{min}}}{C} \]  \hspace{1cm} \text{...(1)}

where, \( N_c \) and \( N_y \) denoted the number of columns and rows; \( C \) is the size of the cell; \( x \) and \( y \) define the positional limits respectively.

B. Compute Slope and Identify Topographic distribution

With reference to terrain surface, slope defines the rate of maximum change in elevation (z)-value from each cell of the input raster surface. Applying the slope to each cell of the raster input data with z-factor=0.3043 (1 foot = 0.3048 meter) three regions viz. land, seawater, and lake are obtained. The results are a direct implication of rate of change in value from the current cell to its neighbors. The basic definition of slope in radians is given as

\[ \text{slope} = \tan^{-1} \left( \sqrt{\left( \frac{dz}{dx} \right)^2 + \left( \frac{dz}{dy} \right)^2} \right) \]  \hspace{1cm} \text{...(2)}

Slope helps to model mountain reliefs. The reconstruction can be used to show the topographical arrangements in 3D space. Lower slopes will correspond to cultivation and residential establishments and higher slopes would categorically belong to forest hills and mountains respectively.
C. Contour Extraction for Structural Identification

In the next step, contours are extracted from the raster dataset (see Figure 5b). Contours are line features (isolines) corresponding to equal values of elevation and thus help in identifying flat and steep regions and valleys and ridge features on the mountains. Converging lines denote ridge and diverging lines denote valley regions respectively. The size of the cell directly affects the quality of contour results and thus its capability in conveying the structural information about the mountains. Smaller the cell size, smoother the contour will be. For smooth results, the values from neighboring cells are used to determine the statistics (max, min, mean, median, minor, major, range, standard deviation, and sum) at the current cell. From all these statistics, mean statistics is most preferred one among others.

Then, the contour list features are computed controlled by the z-value to create the applicable proximity contour. Based on the empirical observations from the region the z value ranges between 10-50 meters (see Figure 5c). With contour list draped onto the 3D model, inferencing the spatial distribution of elevations in the DEM is easier and visually relevant. This defines the foothills and wildlife reach.

D. Exploratory Analysis using Kernel Density Estimation

Next, a clearer geospatial visual understanding of the hills of Rajiv Gandhi National Park region is obtained by performing kernel density analysis on the contours obtained in the previous step. Kernel density gives magnitude per unit area of the feature and thus emphasizes
the relative geospatial positioning of the hill region under investigation. In other words, kernel density estimators provide locally weighted averaging of the distribution. With the test dataset, for density calculations, the planar method is used rather than geodesic method. This is due to the fact that the data set under evaluation represents local area and a projection with relatively correct distance and area measures. Quartic function based kernel[19] is implemented. The default search radius (or bandwidth) for computing the features (mountain region) in a neighborhood around it is defined as follows.

$$R = 0.9 \times \min \left( D_w, \frac{1}{\sqrt{\ln(2)}} \times D_m \right) \times n^{-0.2} \quad \text{… (3)}$$

where $D_w$ denotes standard distance, $D_m$ denotes median distance and n corresponds to the number of points or the sum of population field.

E. Draping and Exporting for Rendering

The final reconstructed 3D surface can be further draped with the satellite image on the 3D reconstructed surface to provide the realistic feel of the mountain region of the national park. The draped image when exaggerated can show the small details more appropriately. The final result is exported for rendering and interactive visualization into VRML format for the independent viewing experience. Custom operations and interaction can be easily performed on VRML model in user friendly manner and thus more useful.

[5] RESULTS AND DISCUSSION

Based on the framework (see Figure 3) and the experimental results, there are several interesting observations. For visual efficiency neighbor assignment, bilinear and cubic convolutions are applied and the reconstructed terrain models are evaluated for visual efficiency and processing time. The nearest neighbor assignment is faster but suffers from visual smoothness and results in the spatial error of the order of one-half the cell size. Bilinear interpolation generates smooth surface (see Figure 4b) by obtaining the new cell value by using the weighted distance average of four adjacent cell centers. Cubic convolution uses 16 nearest input cell centers to fit the curve to generate the new values. Although the result obtained by cubic interpolation was less distorted than the result obtained using nearest neighbor techniques, but it takes more time to process. Also in some cases, outlier points are generated which is undesired.

Computing slope helped in delineating surface into mountain, planar and water regions. A high rate of change in gradient denotes mountain and thus helps in culling away the ground and other less relevant regions. The ground truth verification shows the convergence of accuracy between to 96% to 98% with the exception of some isolated foothill region. Zonal identification contour based on elevation and slope helped in identifying wildlife reach at the foothills. Finally, the use of kernel density (see Figure 5d) highlighted different topographical zone and hence can relate to the degree of interference with urban infrastructure. The central concentric zone defines the safe zone for wildlife with least interference while the outer zone concentrates flat region suitable for human establishments. Some of the other observations are highlighted next.

A. Data sources and related problems:
High-resolution Data requirements: The reconstructed output using raster samples at 30m resolution successfully explains the geographical structure of mountains. However, higher resolution (1m resolution) of remotely sensed data and greater sampling density will improve the results matching with the ground truth.

Mapping problems: Geometric distortion is experienced in output when remote sensed and aerial photographs are used for modeling mountainous region. Distortions are high around high relief region. However, it can be overcome using shadow matching.

B. Ground truth validation issue: Measuring ground truth for such larger area is challenging. Global Positioning System (GPS) was used to physically verify known positions of the mountain region. The accuracy of around 94% is observed for well-defined establishments. The error of 17m to 125m was observed around high slopes.

The final reconstructed and recognized mountain regions of Sanjay Gandhi National Park region is shown in Figure 6.

![3D Solid Model of Reconstructed Mountain](image.png) ![3D Mesh Model of Reconstructed Mountain](image.png)

Figure 6: Reconstruction Results of National Park Region

The distribution of the shape profiles of the mountain shows geometrical high degree of geometrical variation. The contour composition of the mountains of the national park region controlled by the slope is shown in Figure 8 and Figure 9.

![Mountain Contour Length Distribution Graph](image.png)

Figure 8: Object v/s Polyline Shape Length of Surface Mesh

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The performance of the proposed work had produced satisfactory results and has proved to useful in planning activities by understanding geographical structures with a realistic perspective. The accuracy verification of mapping the region was carried out using physically using GPS and known coordinated from Google Maps. The average accuracy was around 97.13%. Largely the result shows that bilinear and cubic convolution based interpolation gives good visual results. The output 3D surface stored as VRML model gives user interactive investigative capability to study and visually map the national park region. Simple statistical measures like slope and contour are found useful in reconstructing complex shapes from raster datasets.

[6] CONCLUSION

The reconstruction of terrain models based on raster data like SRTM DEM has been found good in mapping and reconstructing mountain regions. Bilinear interpolation has been proved to generate good surface approximation even for mountain region exhibiting high variations in slope and elevation. Contour and kernel density helped in identifying, modeling and locating the proximities of affected zones wildlife near foothills. The accuracy of around 97.13% has been obtained for the reconstructed hill region. This work can further used to model for identifying suitable points for infrastructural hubs for managing and controlling activities in the mountains. This work can be extended in future for modeling and visualization of forest on the mountains including foothills and steep slopes. Modeling and reconstruction of local and granular variations of the surface features can be further investigated.

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REFERENCES


