Multi-scale Analysis of Digital Surface Models Based on UAV Datasets

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Abstract: The increasing uses of Unmanned Aerial Vehicles (UAV) and the producing of high resolution Digital Surface Models (DSMs) is leading to a multi-scale result in terrain analysis, prompting new solutions to cope with multi-scale analysis. In this paper we tested three indices — the local variance, texture and fractal dimensions of a same study area with six different spatial resolutions DSM processed from different UAV flights height datasets at 20, 40, 60,120,240 and 360 meters. The higher spatial resolution DSM extracted from 20 meters flight height was set as a base for a series of correlation analysis of the between the three indices to study the generalization at different scales. This approach could help in understanding the spatial resolution changing with scale and it could be used for developing hierarchical DSM scale classifications.

Key words: UAV, GIS, DSM, multi-scale

1. Introduction

In geoinformatics, scale is predominantly considered a function of the resolution of Digital Elevation Models (DEMs) [1, 2].

The fast progress in technologies especially the unmanned aerial vehicles (UAV) and new photogrammetry softwares encourages acquisition and processing of Digital Surface Models (DSM) at ever finer resolutions. The scale dependency of land-surface parameters was noted by Evans (1972) as “a basic problem in geomorphometry” [3]. Meanwhile, the scale dependency of land-surface parameters and land-surface objects has been confirmed by several researches [4-12].

The factor of scale and resolution plays an important role in the uses of digital models in GIS research, the scale may range from micro to macroscale and may be in different levels of measurement, this paper will only discuss the spatial scale with the UAV flight Heights. For the selection of an image with appropriate spatial resolution for a study demand the characteristics examination, especially the changing pattern as a function of changes in scale and resolution.

According to Li Zhilin (1993) [13], based on different kinds of philosophy, three types of approach can be identified to the generation of multi-scale representations for a given DTM (Digital Terrain Model), i.e., critical-points-based, smoothing-based, and scale-driven [13].

Woodcock and Strahler (1987) [14] suggested the use of the local variance method to find images with the optimum scale and resolution.

In their experiment, Woodcock and Strahler (1987) [14] used image datas were degraded to coarser spatial resolution by resampling the neighbors’ cells and the pixel value of the coarse resolution is an average of a group of finer resolution. In our experiment we have 6 DSM for the same study area with different spatial resolution obtained from UAV different heights survey. The effect of scale (spatial resolution) on these surface
models is analysed according to the morphometric indices by calculating their direct indicators of spatial correlation. Therefore, the experiment implemented the opportunities of multi-scale measurement technology based on UAV.

For multi-scale analysis we applied Wood and Strahler’s (1987) [14] method of Local Variance, the texture method measuring surface properties such as coarseness and smoothness, and as a third index of fractal dimension.

2. Study Area and Datasets

Our experimental research was carried out at an area about 2 hectares at a relative altitude of 1700 meter above the sea level, in Zaarour region situated on the western Lebanese mountainous chain (Fig. 1). We choose this bare non urbanized mountainous area because of its representative morphological terrain forms.

The study area with a slight natural slope, represented by bare lands with elements of anthropogenic relief. The inclusion of anthropogenic micro-relief in the studying area due not only to the requirements of representativeness, but the presence of complicating microform for the experimental modeling of the terrain concave and convex smoothed areas.

An autopilot Dji Phantom 3 Unmanned aerial vehicle (UAV), caring a camera of 14 megapixels at a focal length of 3.61 mm flies the study area at different Heights. The flight Heights are measured from the takeoff point of the quad copter; the experiment constituted from 6 missions: FA-20, FA-40, FA-60, FA-120, FA-240 and FA-360 of 20, 40, 60,120,240 and 360 meters height.

The flight path followed by the quad copter was identical for all the flights and it was designed in a mobile application called Litchi (Fig. 2). The printed screen of the Litchi application Fig. 2 shows the flight path of the quad copter, the study area and the flight parameters (coordinates, height, time, etc...). All datasets (photos) of the six missions of different flight heights was processed in Agisoftphotoscan software for the extraction of Digital Surface Models (DSM).
If the camera focal length and the flying height of the UAV are known the scale is determined by this formula:

$$\frac{1}{S} = \frac{f}{H}$$

with $S = \text{scale}$, $f = \text{focal length of the camera}$, $H = \text{flying height}$.

The result of scale calculations for each flight height is listed in Table 1.

Fig. 2 shows six DSM of the study area of different spatial resolutions: FA-20 of 20 meters flight height with a very high resolution data set highlighting all the terrain details even rock textures, passing by FA-60 and ending by FA-360 of 360 meters’ flight height with a very low spatial resolution and high generalization effect with the “disappear” and “growth” of some terrain morphological features.

These 6 DSM can be classified visually from Fig. 3 by rough and smooth; FA-20, FA-40 and FA-60 for rough and FA-120, FA-240 and FA-360 for smooth, also Fig. 3 constitute an interval of scales and smoothness showing the generalization at different scales.

As per Table 1 different flight height lead to different spatial resolution (pixel size); the minimum spatial resolution is 0.37 m which is a high resolution showing all terrain details and a maximum resolution of 4.47 m quite good resolution for geomorphological analysis at a local scale.

After the scales calculation we categorized our data in two categories plans and maps; the first three DSM of flight height 20, 40 and 60 are related to the category of plans and the other are related to the category of geographical maps.

### 3. Materials and Methods

Many scientists, quantitatively discussed the issue of optimal resolution of digital elevation models. Our study summarized the methods expressing relation between UAV flight height and spatial resolution, and they are local variance, texture analysis and the fractal method. The first two methods are relative simple and very useful in practical sense, while the third fractal method was...
dimension method has a great potential in detecting the resolution effects and is used especially in several geosciences researches.

![Multi-scale DSM extracted from UAV photogrammetry methods.](image)

**Local variance** method proposed by Woodcock and Strahler [14] is such a method, originally developed in image analysis, with potential for dealing with scale in DEM analysis [15]. Local variance measures the mean of standard deviation within a 3 by 3 pixels in a moving windows, the mean of all local standard deviation values over the entire image were then used as an indicator of local variability contained by the image.

The local variance is the degree of similarity between the values of two points depending on the spatial distance between them. The longer the distance is, the higher the degree of similarity is, and the smaller the variance is.

According to Schmidt and Andrew (2005), the land surface is hierarchically structured and it can be represented differently across scales for example convex hillslope embedded into a concave hillslope, which in its turn is embedded into a valley. These cases could be detected and seen only on high spatial resolution DSM and are homogeneous relative to scale levels.

In Fig. 4 the variance maps of the study area at FA-20 showing all morphological forms in detail even small concave and convex forms with some finesse in FA-40, the same forms became bigger in size and dimensions. In the last stage of plan categories FA-60 the ridges boarding the roads became more highlighted with disappearance of the small morphological forms. Hence in the second category of scales FA-120, FA-240 and FA-360 the degree of smoothness is increasing with the scale.

**Texture** is a measure of coarseness, smoothness and regularity of the surface [16]; texture analysis can measure the spatial variability of image data, and can improve the statistical separation of the otherwise similarity reflecting surfaces [17]. The differences in
texture for images covering the same area with different scales and resolutions (the case of our study) can indicate the heterogeneity of the scene under observation [17]. In that way we can compare the data between each other, in this case highest texture index indicates the highest variation.

Fig. 4  Variance digital models of the six flight heights.

Texture is calculated by extracting grid cells that outline the distribution of valleys and ridges. Each grid cell value represents the relative frequency (in percent) of the number of pits and peaks within a radius of ten cells [18].

Similar to local variance methods the texture analysis method is also based on the variability of the geographic data change of scale and resolution, and the scale at which the maximum variability occurs is where most of the relief formation processes operate. By finding the maximum variability of the dataset, we could find the operational scale of the geographic phenomenon and therefore we could decide the observational scale of the study.

The texture index in Fig. 5 shows a stability in the morphological forms in the first three scale and an unclear form in the last three level of scales. Consequently, the first three scales allow us to determine the Genesis of the relief-forming processes.

Fractal dimension, the concept of fractals fascinates geographers because all the patterns of nature are too irregular and too fragmented to be quantified using the traditional measure of geometric shapes. In real world curves and surfaces are pure fractals that’s why fractal could play an important role in detecting the scale and resolution effects in remote sensing and GIS.

Eastman (1985) [19] developed a single pass technique for measuring the fractional dimension of lines. The procedure considers each slope segment, to provide evidence of an underlying angularity that can be considered as the generating angle of the fractal form. The formula is based on calculated slopes as follows:

$$D = \frac{\log(2)}{\log(2) + \log\left(\frac{180 - \text{slope}}{2}\right)}$$
We applied Eastman’s method to calculate the fractal dimension of the six DSMs (Fig. 6). As it is known, surface fractal dimension values vary inside the interval between 2 and 3. Empirical studies indicate that the fractal dimensions of curves and surfaces change with the scale and resolution, the scale at which the highest fractal dimension is measured may be the scale at which most of the processes operate [20, 21].

Fig. 5  Texture digital models of the six flight heights.

Fig. 6  Fractal dimension digital models of the six flight Heights.
The fractal dimensions show the roughness and complexity. Goodchild (1980) [20] found that fractal dimension could be used to predict the effects of cartographic generalization; many scientists used fractals to characterize landscape environmental data, soil, topography [11, 22, 23].

The fractal dimension of an image is expected to be lower as the resolution becomes coarser; because coarser resolution is likely to result in low variability in digital surface model, it is argued that the best resolution level for a study is the one that has the highest fractal dimension within a stable scale range, the results of fractal dimensions calculations shown on Fig. 6.

If we compare Fig. 4 the local variance index maps with Fig. 6 of fractal dimensions a high degree of similarity is seen, which indicates the usefulness of the application of indices in this analysis.

4. Discussion and Results

After the application of the three scale indices on the six levels of details a statistical, Table 2 summarizes in values the generalization between them.

| Table 2  | Local variance, texture and fractal dimension statistical values over the six DSM’s. |
| DSM    | Local Variance | Texture | Fractal Dimension |
|        | Min* | Max | Mean | STD | Min | Max | Mean | STD | Min | Max | Mean | STD |
| FA-20  | 0.129 | 0.005 | 0.007 | 0.189 | 0.864 | 0.457 | 0.170 | 2.0 | 2.179 | 2.008 | 0.011 |
| FA-40  | 0.136 | 0.010 | 0.012 | 0.000 | 0.851 | 0.337 | 0.182 | 2.0 | 2.112 | 2.008 | 0.009 |
| FA-60  | 0.143 | 0.015 | 0.017 | 0.000 | 0.75 | 0.333 | 0.157 | 2.0 | 2.067 | 2.006 | 0.007 |
| FA-120 | 0.458 | 0.088 | 0.065 | 0.009 | 0.561 | 0.221 | 0.125 | 2.0 | 2.042 | 2.007 | 0.006 |
| FA-240 | 0.811 | 0.222 | 0.141 | 0.160 | 0.408 | 0.252 | 0.059 | 2.0 | 2.023 | 2.006 | 0.004 |
| FA-360 | 0.985 | 0.414 | 0.231 | 0.211 | 0.401 | 0.295 | 0.050 | 2.0 | 2.016 | 2.005 | 0.003 |

*Min – minimal value, Max – maximum value, Mean – mean of the values, STD – standard deviation of the values.

The local variance maximum values increase with the flight Height and the scale, the standard deviation and the mean are increasing proportionally in all scales, contrary to local variance values, texture and fractal dimensions maximum, mean and standard deviation are decreasing with the flight Height and the scale as a result of the smoothing effect.

To determine the spatial distribution of the analysed indices at different scales, we applied a simple and effective tool — spatial correlation.

A correlation scatterplots of all the elevation values of each DSM compared to the main DSM the FA-20, from figure 6 we can see a good correlation between FA-20 and FA-40 (coefficient of determination $R^2$ is equal to 78.7%), which decreases between DSM FA-20 and FA-60 ($R^2 = 65.4$).

The scatterplots of the last three levels show a very poor degree of similarity comparing to FA-20 in fact, it shows a lack of connection between DSM at various levels of scale (Fig. 7). It means we are losing accuracy and we have a big generalization lost in the maps category, built using the UAV. Similar results were obtained when comparing the estimated parameters of the texture.

When interpreting the values of local variance, we consider the following: If the spatial resolution is considerably finer than the objects in the scene, most of the measurements in the image will be higher correlated with their neighbours and the local variance will be low. If the objects to be studied approximate the size of the resolution cells, the value tend to be different from each other and therefore the local variance increases. The resulted correlation values in Table 3 of DSM and texture are decreasing proportionally with the scale otherwise FA-20/FA-120 at fractal and local variance constitute a barrier of values due to a raised amplitude in R2 values which give a similarity in scale changes between fractal and
local variance in a way and in another way between DSM and Texture.

The correlation between the values of the local variance has a statistical reliability (significance) only for the DSM with a spatial resolution close to FA-20 and FA-40. For cases with large differences in spatial resolution, these indices become essentially independent on the same site. We can conclude that the correlation in local variance decrease with flight Height.

Table 3  correlation analysis values between different scales of different indices.

<table>
<thead>
<tr>
<th>Values of R2%</th>
<th>DSM-FA-20</th>
<th>Fractal</th>
<th>Local Variance</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA-20/FA-40</td>
<td>78.71</td>
<td>63.9</td>
<td>71.79</td>
<td>78.68</td>
</tr>
<tr>
<td>FA-20/FA-60</td>
<td>65.39</td>
<td>24.95</td>
<td>25.09</td>
<td>65.28</td>
</tr>
<tr>
<td>FA-20/FA-120</td>
<td>40.03</td>
<td>27.04</td>
<td>26.07</td>
<td>39.49</td>
</tr>
<tr>
<td>FA-20/FA-240</td>
<td>14.01</td>
<td>20.72</td>
<td>18.39</td>
<td>13.15</td>
</tr>
<tr>
<td>FA-20/FA-360</td>
<td>0.78</td>
<td>13.55</td>
<td>11.89</td>
<td>0.79</td>
</tr>
</tbody>
</table>

5. Conclusion

Drones — a relatively new survey instrument of the earth’s surface and DSM processing. For a representative area in the mountains of Lebanon according the drone experiments have been performed with variable flight heights (scale) with DSM processing and calculation of derived morphometric indices.

Scale and resolutions effects have been and will continue to be an important issue in geographic research. It is essential to have a good understanding of the effects of scale on the analysis results. We tested in these paper three morphological indexes (local variance, texture, fractal dimension) that can be used to detect the scale and resolution effects.

The results showed a weak relationship of spatial characteristics to compare the images to scale plans and maps. Simultaneously, the survey showed that the characteristics of the local variance and texture are good indicators to determine the optimal spatial resolution of the morphometric analysis of the earth’s surface.

References


