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ACCURACY OF 3D (THREE-DIMENSIONAL) TERRAIN MODELS IN SIMULATIONS

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ABSTRACT:

The usage of realistic three-dimensional (3D) polygon terrain models with multiple levels of detail (LOD) is becoming widespread in popular applications like computer games or simulations, as it offers many advantages. These models, which represent an actual location in the world, are essential for the simulation-based training of military vehicles like planes, helicopters or tanks. Because training scenarios on this kind of simulations are used to observe or to hit a target on the modeled location. In addition to that, driving the behavior of terrestrial vehicles is influenced by the terrain properties like slopes, ramps, hitches, etc. because of the direct interaction with the ground. For this reason, the terrain models in the simulation scene should not only display the textures realistically, but also represent an accurate morphology; meaning the terrain altitudes should be modeled as correct as possible. Such terrain representations can be created by using Digital Terrain Model (DTM) for the geometry and satellite images for texturing. The geometry models are in the form of polygonal meshes through the triangulation methods. However, the accuracy is influenced by some parameters. Using insufficient (under-refined) triangles during the 3D modeling causes missing of some altitude vertices. That means these points will not be present in the model. Consequently, it can be thought that the number of triangles should be increased for a better geometrical fidelity. Nevertheless, it is not always correct as the usage of too much (over-refined) triangles can also cause errors, especially in terrains with almost vertical faces (like cliffs). In addition to that, the performance of the system deteriorates drastically through the increase in the number of triangles, as the computational complexity is also getting higher.

KEY WORDS: *3D, Accuracy, Simulation Model, Digital Terrain Model, Real Time Rendering*

1. INTRODUCTION

The convergence to the reality of 3D terrain models, which could be created quickly with the help of satellite images and DTMs, depends on not only the graphical quality but also the geometrical detail level of the surface. The altitude information in the DTMS is used in order to create triangular surface geometries during the 3D modeling with software tools (Smelik et al., 2009). The terrain model can be produced with several sub-models with different quality levels, which are called LODs (Level of Detail). The visual scene is switched between these LODs to ease the representation of the graphical environment (Pregasis, 2016a). There are different numbers of triangles in every LOD. The number and form of the triangles influence the surface structure, so the geometrical accuracy is affected by them (Tariq, 2009).

To display these influences, an example terrain from Istanbul Bosporus area has been modeled as 3D using three different level of details. In the study, ASTER DTM with a 15m resolution for the altitude data and Quickbird satellite images for surface texturing have been used. Ground control points are selected for 3D model and DTM data and the altitude differences are measured in order to calculate "Root Mean Squared Error (RMSE)" of 3D model LODs. The least error measurement is gathered in the middle level of detail (2. LOD). The interpretation of the error sources at every level has been provided at the conclusion. Presagis Terra Vista (Pregasis, 2016b), Creator (Pregasis, 2016a) and Global Mapper (Blue Marble Geographics, 2016) software tools have been used for the modeling and analysis in this study.

In the study, realistic 3D terrain models with three LODs in a simulation scene are examined and accuracy of altitudes and root mean squared errors (RMSE) are calculated for every detail level. After the examination of the relationship between the triangle amount and RMSE, it was seen that the lowest inaccuracy (best representation) occurs in the intermediate detail level (2.LOD). In conclusion, two methods are introduced to determine the amount of the triangles. The first one is the comparison of the altitudes with the real values after the interpolation, which is the traditional way. The second method is to compare the vertical areas between the vertices instead of altitudes. In this study, software tools, Presagis-Terra Vista for modeling applications and Global Mapper for GIS applications, are used.

2. METHODOLGY AND APPLICATION

For the application, the modeling has been done with ASTER DTM data in 15m resolution and texturing has been applied to the models from Quickbird satellite images. The surface of the model between the coordinates 41° 9.43977' K - 41° 10.87128' K and 29° 5.22732' D - 29° 6.29880' D has been examined for the error analysis (Figure 1). The models have been produced with Terra Vista software tool of Presagis (Pregasis, 2016b) (Figure 2).

UTM projection coordinates have been selected for the outputs and WGS 84 ellipsoid has been taken as the horizontal reference, therefore all data has been converted to this system before utilizing.

The models have been created in three LODS. The number of the triangles for the LODs are given in Table 1.

Table 1. Number of triangles for LODs

Level of Detail (LOD)	**Triangle amount**
Low (1)	121
Middle (2)	527
High (3)	7250

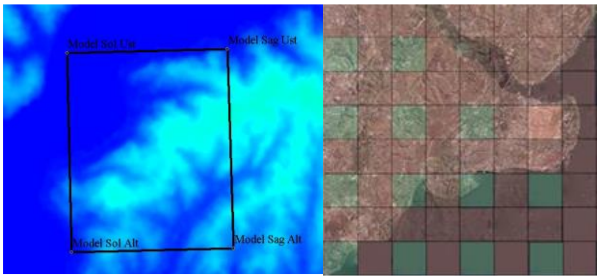

Figure 1. ASTER DTM data from the selected model surface and modeling process in Terra Vista software tool

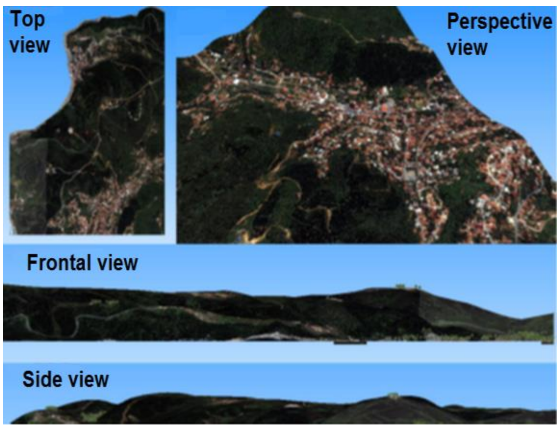

Figure 2. Different perspective views of the resulting model.

11 ground control points, which are spread in different positions on the 3D model, have been selected for the RMSE of the LODs Figure 3). They are chosen from the most and least sloping positions to show the triangulation errors as a result of the modelling.

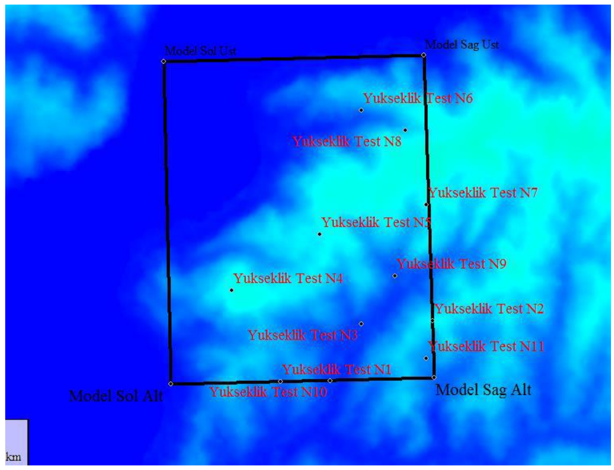

Figure 3. The distribution of ground control points

The measurements of the altitude for ground control points for each of the LODs in the model and their corresponding points on the DTM has been shown in Figure 4.

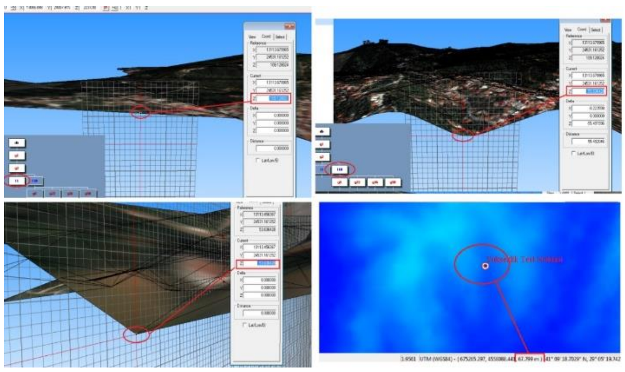

Figure 4. Altitude values of ground control points in LODs and DTM (lower right)

The RMSE results of the LODS in the model has been given in Table 2.

Table 2. RMSE results of the LODs in the 3D model

Ground control points	3D Model LOD2 Z	3D Model LOD2 Z	3D Model LOD3 Z	Source Aster DTM Z (m)	3D Model Error 1 LOD 1-DTM (m)	3D Model Error 2 LOD 2-DTM (m)	3D Model Error 3 LOD 3-DTM (m)
N1	109.13	53.64	53.64	66.28	42,85	-12,64	-12,64
N2	53.85	154.26	154.26	163.26	-109,41	-9	-9
N3	31.20	33.20	31.20	40.46	-9,26	-7,26	-9,26
N4	47.27	175.40	188.32	180.9	-133,63	-5,5	7,42
N5	19.10	155.10	166.31	163.505	-145	-8	3
N6	72.86	81.80	71.80	78.32	-5,46	3,48	-6,52
N7	164.84	160.52	166.85	168.77	-3,93	-8,25	-1,92
N8	150.99	132.00	128.00	134.62	16,37	-2,62	-6,62
N9	41.30	49.09	48.80	55.78	-14,48	-6,69	-6,98
N10	27.29	25.30	24.50	33.94	-6,65	-8,64	-9,44
N11	53.00	87.99	78.00	91.36	-38,36	-3,37	-13,36

∑ (Ln –Dn) ^ 2	54669,70 603	612,17 1125	795,78 6425
∑ (Ln –Dn) ^2 /n	4969,97 3275	55,65 19205	72,34 422045
RMSE (√ (∑ (Ln-Dn) ^2 /n)	**70,5 (m)**	**7,5 (m)**	**8,5 (m)**

As seen in the table above, the least error has been gathered from the middle LOD (2.LOD). The error sources, which are different at every level, has been discussed in the next section.

3. RESULTS AND RECOMMENDATIONS

Each of the error amounts can be associated with different causes. Essentially, the vertical correctness in the terrain models is related closely with the DTM resolution, because altitudes of vertices are gathered from the corresponding points on the DTM during the automatic triangulation. Other than that, the amount of triangles influences the error amount as explained in the following.

3.1. Under-refined triangles/polygons

Under-refined triangles are one of the sources in the low level of detail (1.LOD). Terrain projection algorithms, which instantiate the data on the height map, encounters this problem at most. The number of triangles/polygons to model the terrain should be increased to gather better quality, however, the vertex selections are defined in similar height values. For example, if high-frequency height maps (raster format DTM) are considered, the difference of the altitudes for two adjacent points should be calculated. It is not possible to obtain any quality improvement when these points have the same height value. However, there might be some points on the surface which are not regarded (Blue Marble Geographics, 2016).

The surface, which lays on the red line in the figure, cannot be represented on the terrain as the peak point represented by the bright white pixel was not taken into account, and the calculation assumes no height difference in the model. A pre-scanning on the height map can be made to check the frequencies and mesh resolution can be adjusted to decrease this kind of error. It is also mostly enough to select the triangle vertices carefully aware of this problem. Like if one of the vertices was selected in the middle of the v0-v1 line in Figure *5*, such problem would not occur.

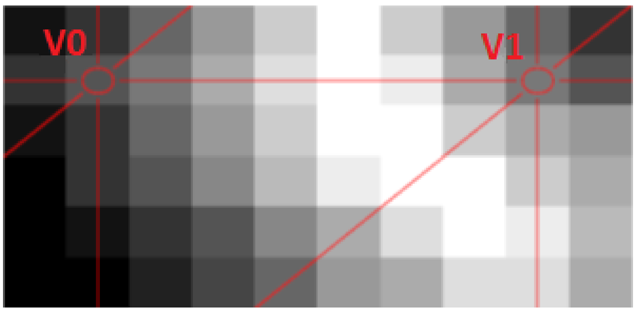

Figure 5. The surface between v0 and v1, which is not regarded.

3.2. Over-refined triangles/polygons

Over-refined triangles are the reason of the error in the high LOD (3.LOD). This error happens during the elimination of extreme height differences in the DTM. When optimization algorithm (automatic triangulation) try to divide an edge, the situation in takes place.

The optimization algorithm in the figure above tries to assign new vertices on the edge between v0-v1 points to improve the accuracy of the modeling for the height differences. In this example, the resolution of the height map is relatively low, there is no new data to gather and optimization process continues till the same height value is gathered from the pixel on the height map (Figure 6).

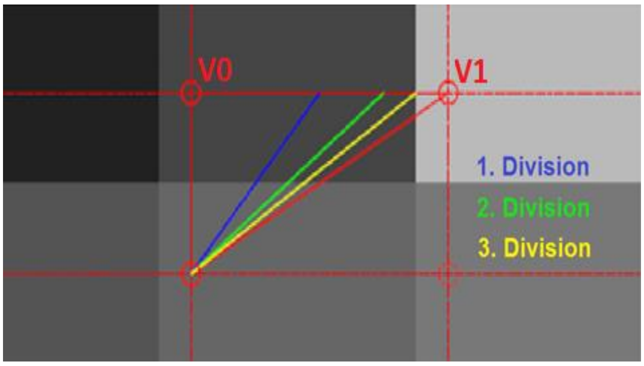

Figure 6. Division of the edge between v0 and v1 points

As the problem takes place on the meshes of a low-resolution height map, the best solution is to abort the optimization process as no new data can be gathered. In every loop of the calculation, the resolution of the surface mesh is doubled, because the distance between vertices is halved. When r_t is the resolution of the height map and r_m is the initial resolution of the mesh, the number of calculation loops can be found as;

$$2^n . r_m = r_t$$
$$2^n = \frac{r_t}{r_m}$$
$$n = log_2(\frac{r_t}{r_m})$$

If the number of optimization loops is more than the n number, the resolution of the mesh in the model is more than the source resolution and it is not necessary to continue with the optimization. However, it is not always trivial to avoid over-refined triangulation. Especially, this problem occurs on cliff-like sloping terrain structures and other similar almost vertical faces. Every vertex assignment on the edge should be done considering the error increase. Considering the position function $p: \mathbb{R}^2 \mapsto \mathbb{R}^3$" for the vertices on the global coordinates, the equation can be written for two vertex points $v_0, v_1 \in \mathbb{R}^2$ and a constant height error ε:

$$\left\| \frac{p(v_0) + p(v_1)}{2} - p\left(\frac{v_0 + v_1}{2}\right) \right\| < \varepsilon$$

If the assigned vertex point does not decrease the convergence error more than ε value, it is not necessary to make the assignment. But in a situation like in Figure *7*, it is not possible to correct assignment points with the interpolation. New vertices are created in every optimization loop as a result, which results in a continuous execution without an end and distorted surfaces correspondingly.

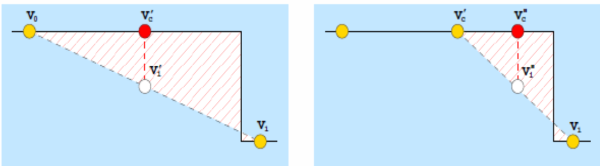

Figure 7. Over-refined triangle error on keen vertical faces

There are two ways to avoid such surface defections. The first solution is to measure the resulting area after the optimization instead of the height difference. In Figure *7*, the dashed surface shows area before and after assignment of the vertex v_c'. Vertex assignment reduces the area, so the error lessens. However, this method increases the amount of calculations and affects the projection performance drastically.

If performance is significant for the application, reducing the error constant ε and limiting the number of optimization loops provide a good solution, as it is the second way to reduce the error (Schmiade, 2008).

4. CONCLUSION

The terrain models in simulation applications should display the textures realistically, and represent accurate morphology, as these properties are essential for user perception and success of the simulation training. The realistic visualization of 3D terrain models, which are generated through satellite images and DTMs, is based on the graphical quality and the geometrical detail level of the surface (LOD). There are different numbers of triangles in every LOD.

A terrain model from the coordinates 41° 9.43977' K - 41° 10.87128' K and 29° 5.22732' D - 29° 6.29880' D has been examined to analyze the effect of LOD to the accuracy. The RMSE results of the LODS in the model have shown that the best results have been gathered from the 2. LOD (medium quality). There are two causes for that. The rough modelling has the problem of under-refined triangulation, and the fine modelling is affected by the phenomena of the over-refined triangulation. These effects should be taken into consideration for successful modelling.

This paper has primarily researched the triangulation-related issues affecting the quality of the terrain models. It should be forgotten that that is not the only parameter for the realistic representation. For example, source height maps are also an essential factor. Further researches might be useful to find out the influence of such elements.

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