

# Digital Terrain Model Interpolation for Mobile Devices Using DTED Level 0 Elevation Data

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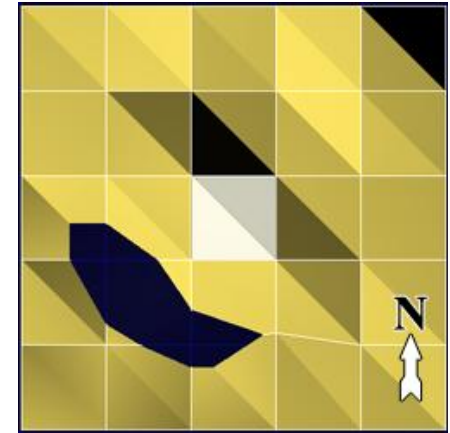
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# Digital Terrain Elevation Data

3D Digital Maps of Earth for elevation values at certain longitudinal and latitudinal positions.

- DTED maps consist of a square grid structure of cells covering the surface of Earth, with terrain elevation values sampled at the intersection points.
- There are three detail levels: Level0, Level1, Level2. DTED Level 0 contains least amount of detail while requiring the least amount of storage space.
- Higher levels require several gigabytes to represent the whole world, while at most a few hundred MBs will suffice for DTED Level 0 storage, depending on data types used in the datafiles.

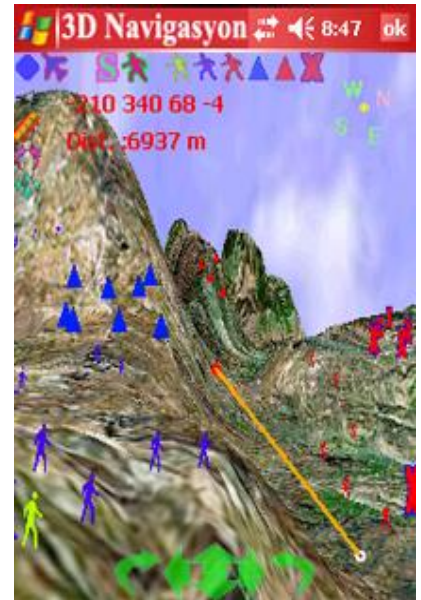


Top view of a sample DTED level 0 grid of 3D terrain cells.

# 3D Mobile Navigation

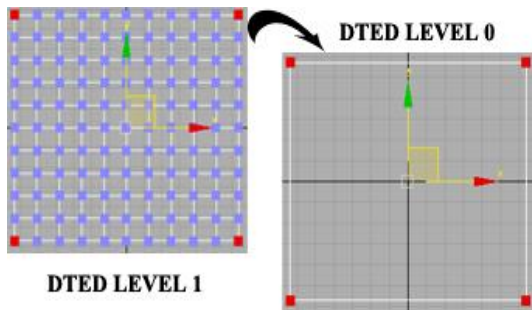


- A 3D Mobile Navigation application has been developed for civil and defence uses.
- Mobile devices certainly have much less computation and storage capacity.
- Digital Terrain Map used in the application has 240 meter resolution and covers a mountaneous area of 14400 km<sup>2</sup>.
- Capacity limitations lead to usage of DTED level 0 type of digital map in mobile handheld device applications.



# Level 1 to Level 0

- Level 0 is generated from Level 1 and distance between two points in Level 0 is nearly 1 km.



Cell conversion from DTED level 1 to DTED level 0.

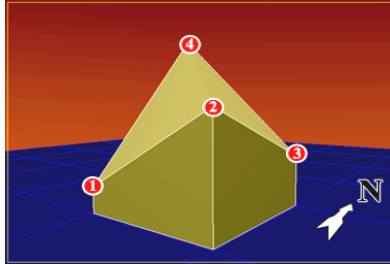
- Each cell in DTED Level 0 contains 7 elevation values for each cell:

- 4 elevation values corresponding to **corner points** of the level 1 cell,
- 1 elevation value for the **maximum** elevation within the level 1 cell,
- 1 elevation value for the **minimum** elevation within the level 1 cell,
- 1 elevation value corresponding to the **average** of all points in the level 1 cell.

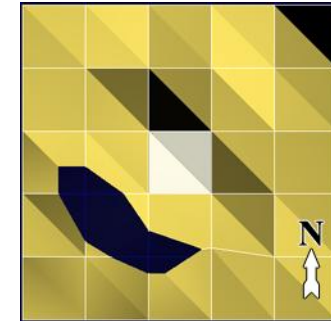
- Although locations of 4 corner points are known, other 3 elevation values have no specific position value within the Level 0 cell.
- In this work, the maximum and minimum elevation points are located in the cell and the rest of the points are interpolated with respect to the average elevation value, using these 6 points.

# 3D Rendering with Corner Points

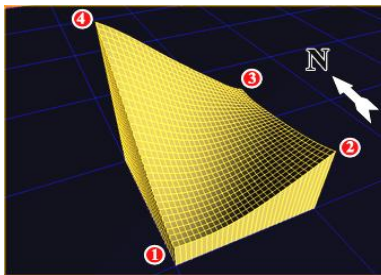
Using the DTED data as is will result in planar surfaces.



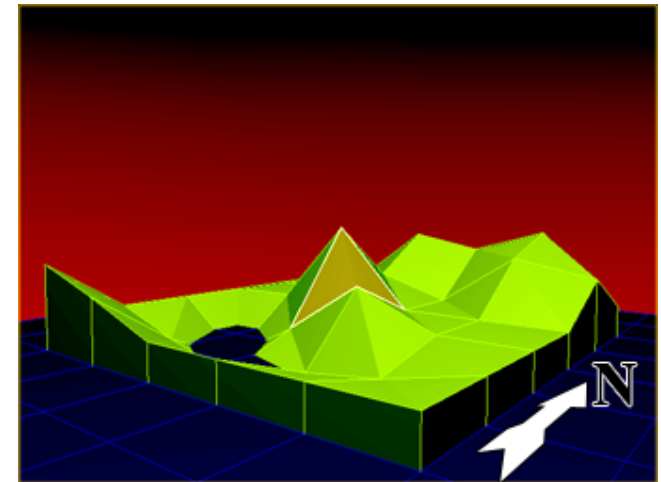
Sample cell with corner points numbered



Interpolation with respect to 4 points provides a smoother surface.



Sample smooth interpolation with 4 corner points

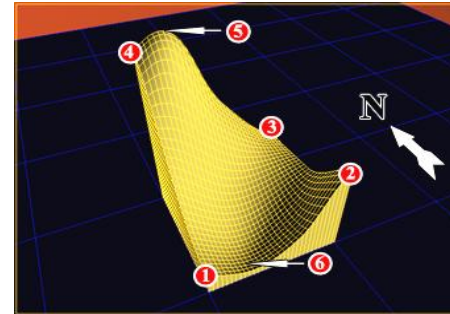
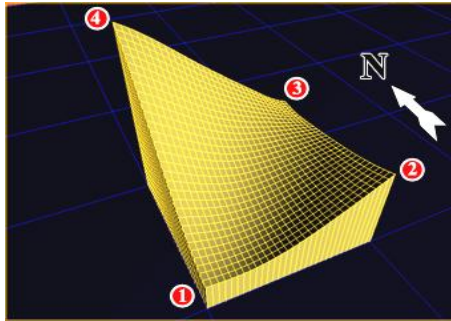


Terrain cells in 3D view based on corner points

# Using Maximum and Minimum Points

DTED Level 0 cells contain maximum and minimum elevation values of the corresponding DTED level 1 cell.

Locating these points will improve interpolation of the surface in terms of average elevation of the interpolated terrain.

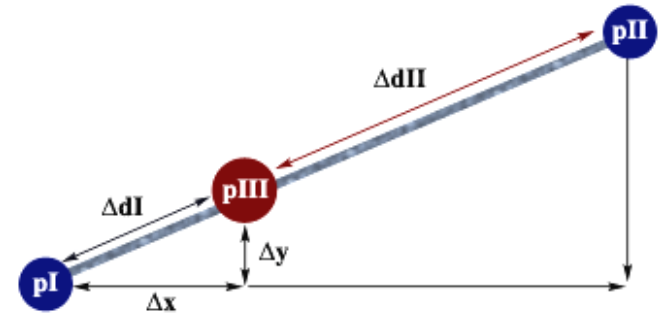


Interpolation after maximum and minimum points located according to Singular Positioning

# Singular Positioning

DTED Level 0 cells contain maximum and minimum elevation values of the corresponding DTED level 1 cell.

Locating these points will improve interpolation precision of the surface in terms of average elevation of the interpolated terrain.

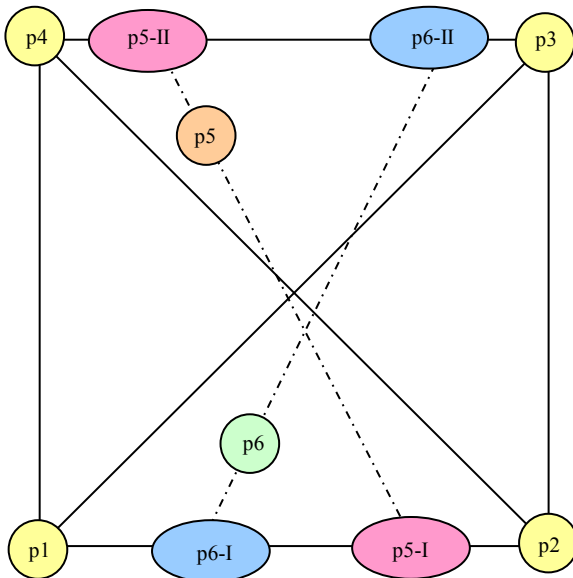


Locating Segmentation Points. (Points Projected on x-y Plane)

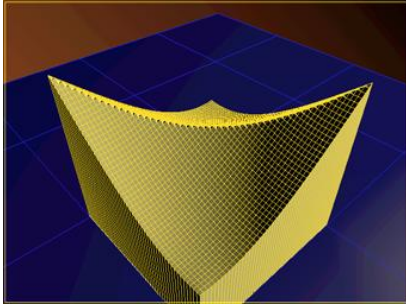
In order to locate maximum or minimum point within the cell, segmentation points are generated with respect to elevation differences of corner points from the maximum or minimum point.

As an example, p5-I and p5-II are located in the cell and they are segmented once more to obtain p5, namely the maximum point. Similarly p6 is an example to the minimum point.

***The smaller difference has a corner point from the maximum or minimum point, the closer it is to the maximum or minimum point.***



# Circular Positioning

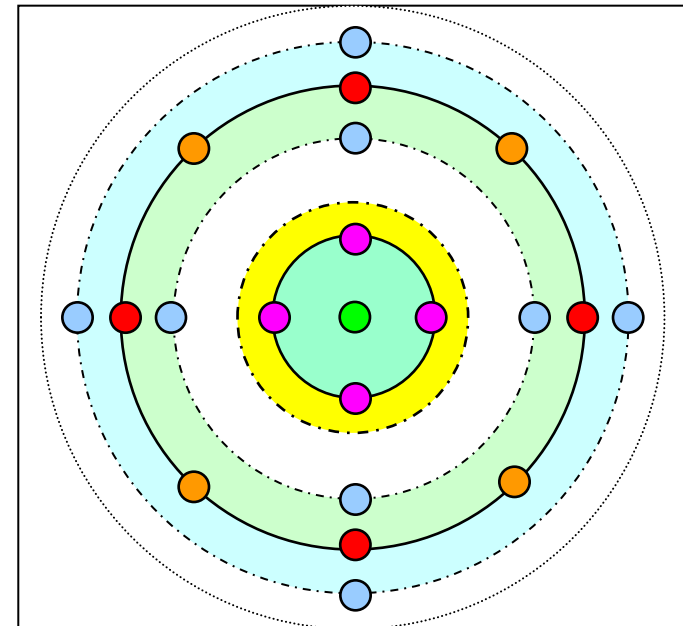


If opposite corners have same elevation values, (NW point has same elevation with SE point and NE has same elevation with SW), then **maximum** and **minimum** points are both located at the **same coordinates**, namely the center of the cell!

For such conditions, *circular positioning of several maximum and minimum points* method is utilized.

Center of the cell is elevated as minimum (or maximum), surrounded by four maximum (or minimum) points, with several control points around these points.

Control points are used to keep overall average elevation of the interpolated cell consistent with the original DTED level 1 cell.

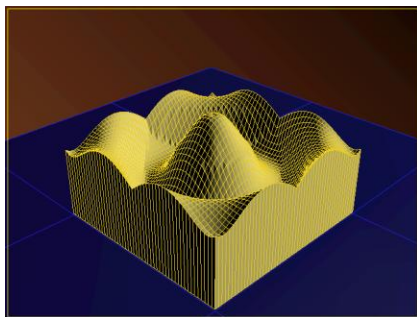
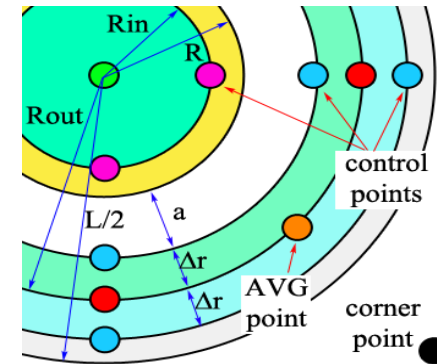




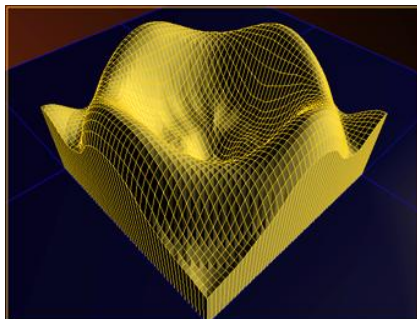
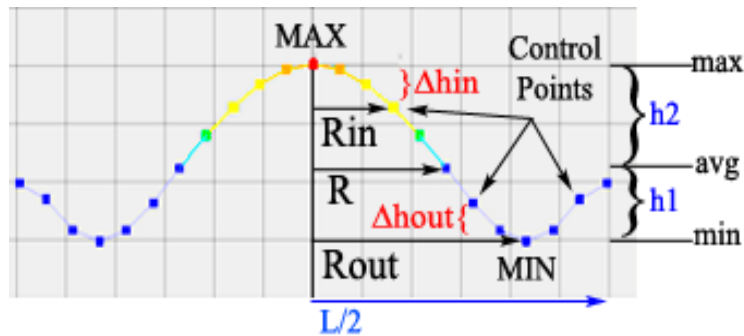
# Circular Positioning

If  $AVG - MIN$  is smaller than  $MAX - AVG$ , then most of the cell area is closer to the MIN point, below the average elevation.

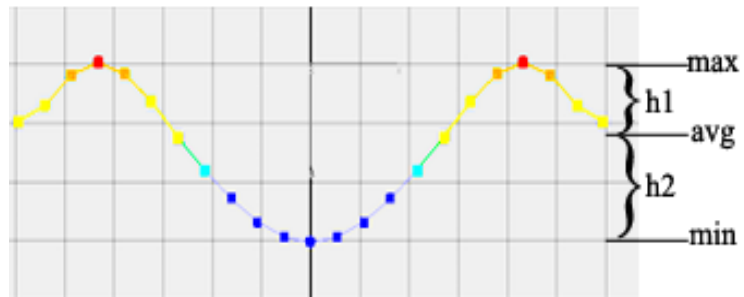
Placing the maximum point in the center of the cell, and four minimum points on an exterior circle will result in such cell interpolation.



$MAX - AVG > AVG - MIN$

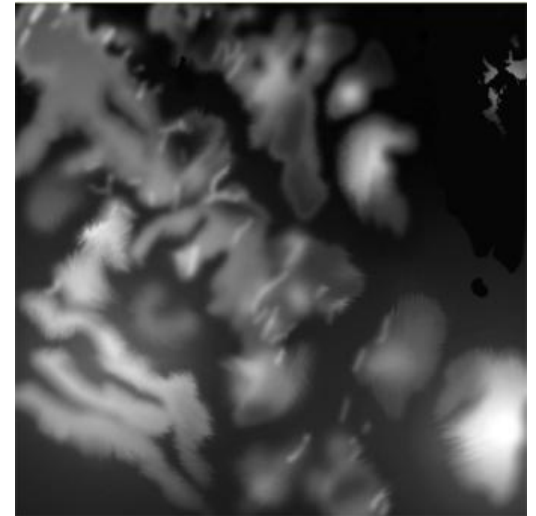


$MAX - AVG < AVG - MIN$



With all control points and parameters explained in the paper, central cross sections of both scenarios can be illustrated with this image.

- Even though a very small percentage of the cells within the sample area mathematically require circular positioning, we utilized this method in the cases where the maximum and minimum points are too close.
- The control points in circular positioning are 3 times more than singular positioning. This method provides even better results than singular positioning.
- As matrix multiplication and inversion with mobile processors will be more costly, the amount of circular cells should be kept reasonable.



Visualization of digital map of the Sample region with 14400 cells

# Results of Interpolation

- Based on the Inverse Distance Weighing interpolation, the proposed technique yields better interpolation results compared to the case that utilizes only the available corner points of cells.

**Table 1** Closeness to real average.

Cell Size (points)	% Of Cells, Where Each Method Finds Better Average			Mean And Std Deviation Of Average Value Difference For Each Method			
	IDW	<b>IDW extra</b>	Equal Distance	Mean for IDW	Std.Dev. for IDW	<b>Mean for IDW extra</b>	<b>Std.Dev. for IDW extra</b>
6x6	3.55 %	<b>93.69 %</b>	2.76 %	-57.74m	45.38m	<b>-40.7 m</b>	<b>39.05m</b>
11x11	2.28 %	<b>96.67 %</b>	1.06 %	-68.72m	52.13m	<b>-44.1 m</b>	<b>43.38m</b>
26x26	1.82 %	<b>97.63 %</b>	0.56 %	-77.39m	56.58m	<b>-42.4 m</b>	<b>43.76m</b>
51x51	1.57 %	<b>97.83 %</b>	0.60 %	-81.47m	58.35m	<b>-39.6 m</b>	<b>42.34m</b>

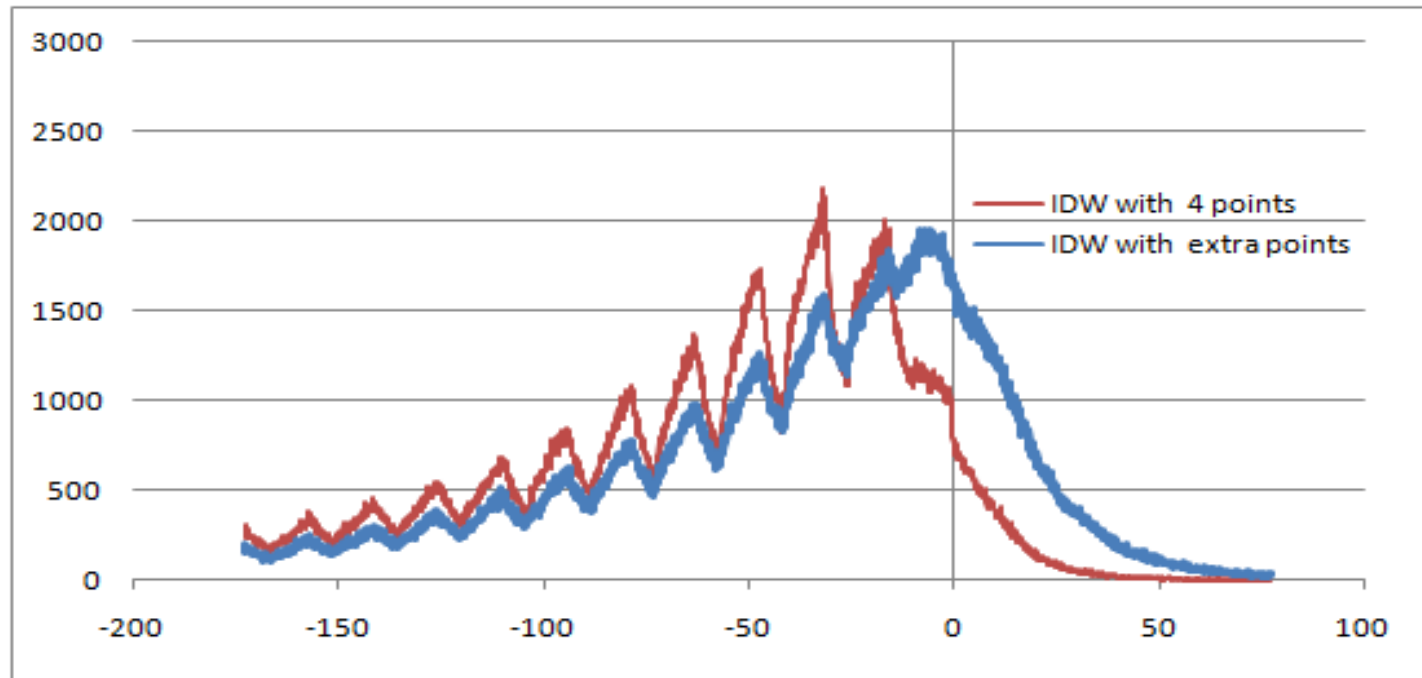
## Closeness to Real Elevation Values of Interpolated Points

Cell Size (points)	% Of Cells, Each Method Finds Elevation Value Closer To Real Elevation Values			Mean And Standard Deviation Of Elevation Value Difference For Each Method			
	IDW	IDW extra	Equal Distance	Mean for IDW	Std.Dev. for IDW	Mean for IDW extra	Std.Dev. for IDW extra
6x6	17.30%	<b>46.38%</b>	36.32%	-57.40m	68.50m	<b>-40.52m</b>	<b>63.05m</b>
11x11	16.20%	<b>57.30%</b>	26.49%	-68.35m	71.25m	<b>-43.84m</b>	<b>63.78m</b>
26x26	14.10%	<b>67.84%</b>	18.06%	-76.99m	72.91m	<b>-42.18m</b>	<b>62.03m</b>
51x51	13.16%	<b>73.09%</b>	13.75%	-81.07m	73.72m	<b>-39.46m</b>	<b>60.24m</b>

Percentage of points with interpolated elevation differences less than 50 and 20 meters from the real elevation values.

Cell Size	Total Points	IDW 50m.	IDW 20m.	IDW Extra 50m.	IDW Extra 20m.
6x6	518,400	58.39%	33.30%	<b>66.72%</b>	<b>42.67%</b>
11x11	1,742,400	50.46%	23.68%	<b>64.03%</b>	<b>37.39%</b>
26x26	9,734,400	43.35%	17.68%	<b>64.91%</b>	<b>37.06%</b>
51x51	37,454,400	39.67%	15.76%	<b>66.43%</b>	<b>37.97%</b>

# Distribution of point elevation difference values. (Number of points vs. meters)



# Conclusions

- Adding more points to the four corner points of each DTED Level 0 cell data, it is possible to obtain better interpolation values for elevations of unknown points.
- Using inverse distance weighting algorithm with additional reference points, we obtain a closer average value for an entire cell, to the real cell average, in more than 90% of 14400 sample cells, compared to IDW algorithm applied only to four corner points of DTED Level 0 data.
- This algorithm will be utilized in the mobile implementation of a 3D Navigation system.
- For the time being, the application uses static points at a resolution of 240m and this algorithm will bring in the flexibility of resolution variability to be used in civil applications.

## Acknowledgments

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Thank you for listening..

Any questions and remarks ?