Efficient interpolation of LiDAR Altimeter datasets in the obtention of Digital Surface Models (DSM)

III Modelling Week UCM

Problem proposed by StereoCarto, S.L.

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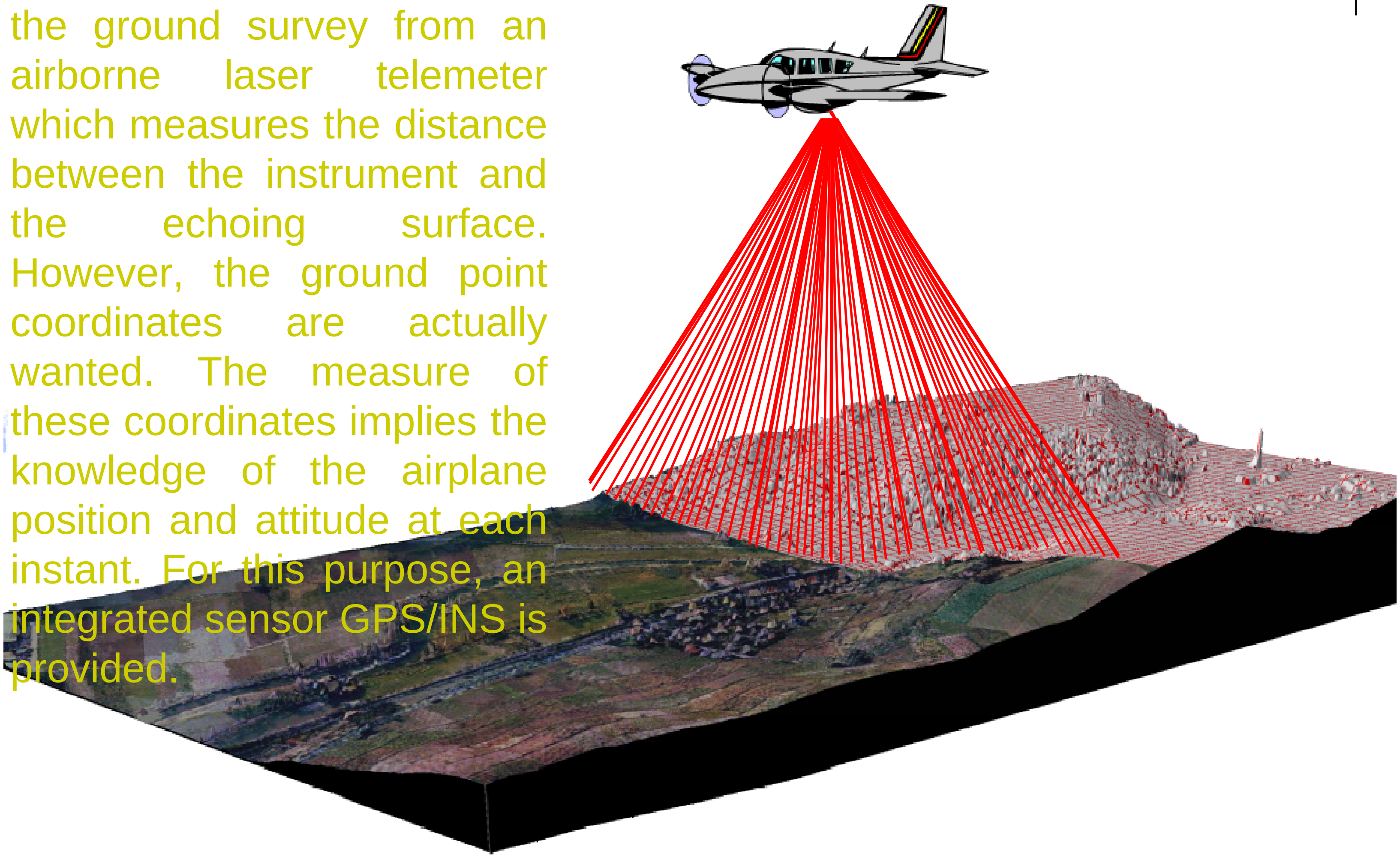
LIDAR TECHNOLOGY

The Airborne Laser Scanning (ALS) technology is based on the ground survey from an airborne laser telemeter which measures the distance between the instrument and the echoing surface. However, the ground point coordinates are actually wanted. The measure of these coordinates implies the knowledge of the airplane position and attitude at each instant. For this purpose, an integrated sensor GPS/INS is provided.



EXPOSITION OF THE PROBLEM

The principal aim is to develop a Digital Elevation Model (DEM) by filtering points that represent terrain objects by interpolation. This leads to two main problems:

1. The first is how to generate a regular grid to reduce such volumes of data in order to get a more effective model.
2. The second is try to reduce the density of measured data which implies a more efficient flight in terms of height and time of survey, and therefore a less expensive project.

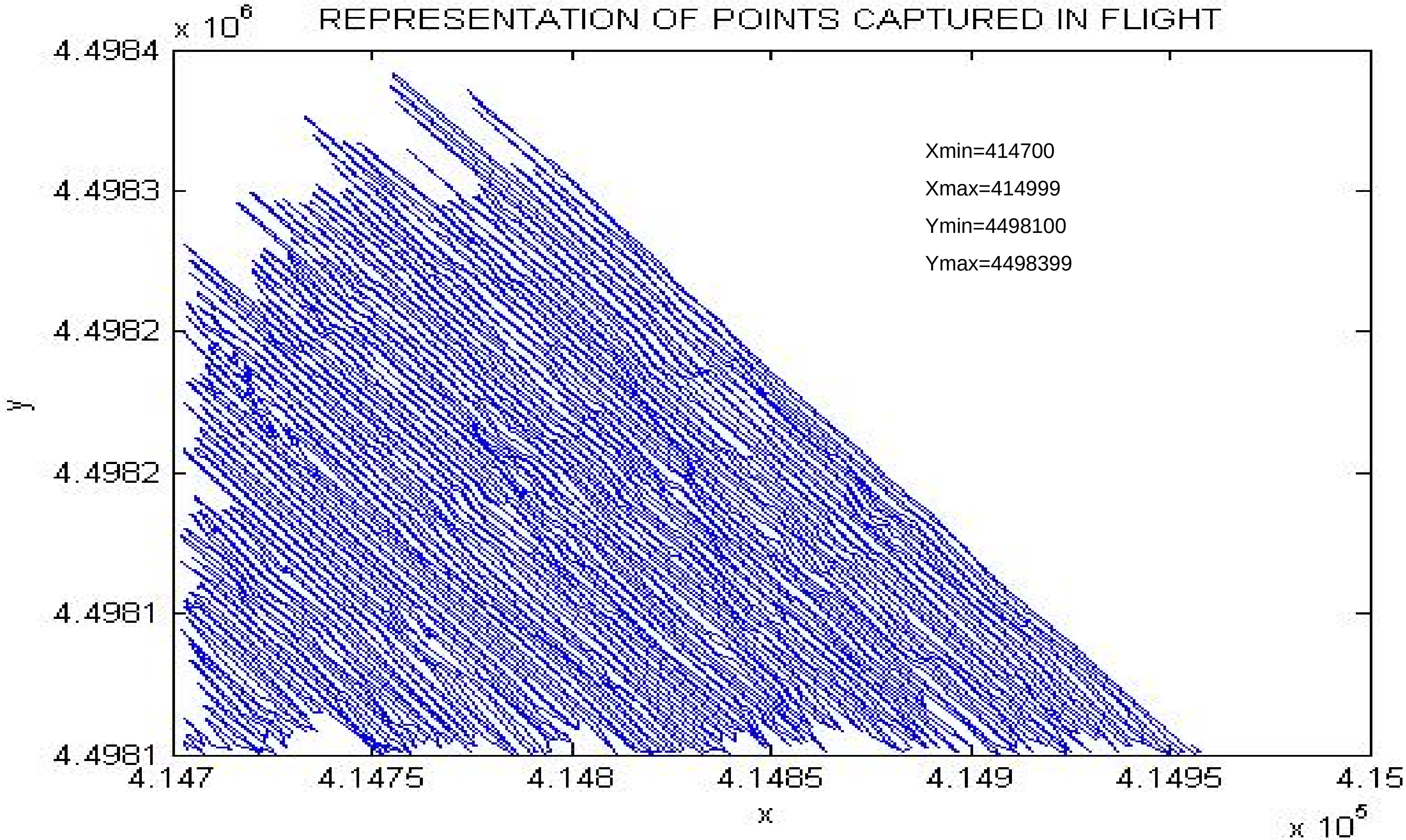
SCOPE OF THE WORK

- Is there a way to reduce the density of the data so that data loss is not relevant?
- Consequently, is it possible to get the same Digital Elevation Model by a flight with higher altitude to capture a smaller number of points, and thus reducing the cost?

METHODOLOGY

- The LIDAR data has been randomly split into a prediction data set and a validation data set
- A serie of DEMs has been generated using linear and nearest neighbour interpolation at spatial resolutions of 1 m and 1.5 m
- Prediction data sets has been randomly reduced to generate a serie of DEMs
- To eliminate initial data we use the test based on the tolerance given for the problem.
- We have developed a software tool using MATLAB to solve the points above mentioned.

WORKING OUT OUR DATA



DATA REDUCTION ALGORITHM

- In order to test how we can reduce the density of points, it’s necessary to make interpolations with different number of points. That’s why we have designed a program that extracts a given number of points at random.
- The data are included in a matrix of 3 columns (coordinates *x, y, z*) and as many rows as observations are taken.
- To select a subset of observations we use a serie of uniformly distributed random numbers for the resulting data which are still scattered in the same manner as the original.
- Since the simulated random values may be repeated, it must be checked at every step of generating the random value has not been previously selected.

DATA REDUCTION ALGORITHM

```
% fix the number of points to extract
n = 100000;
ind_selec = [];
% generate n indexes
for i=1:n
    enc = false;
    % repeat the process while the random indes is already included
    while enc == false
        aleat = fix(unifrnd(1,size(datos_iniciales,1),1,1));
        aux = sum(ind_selec==aleat);   %aux=1 => included
        if aux==0
            enc = true;
            ind_selec = [ind_selec;aleat]; %#ok<AGROW,AGROW>
        end
    end
end
```

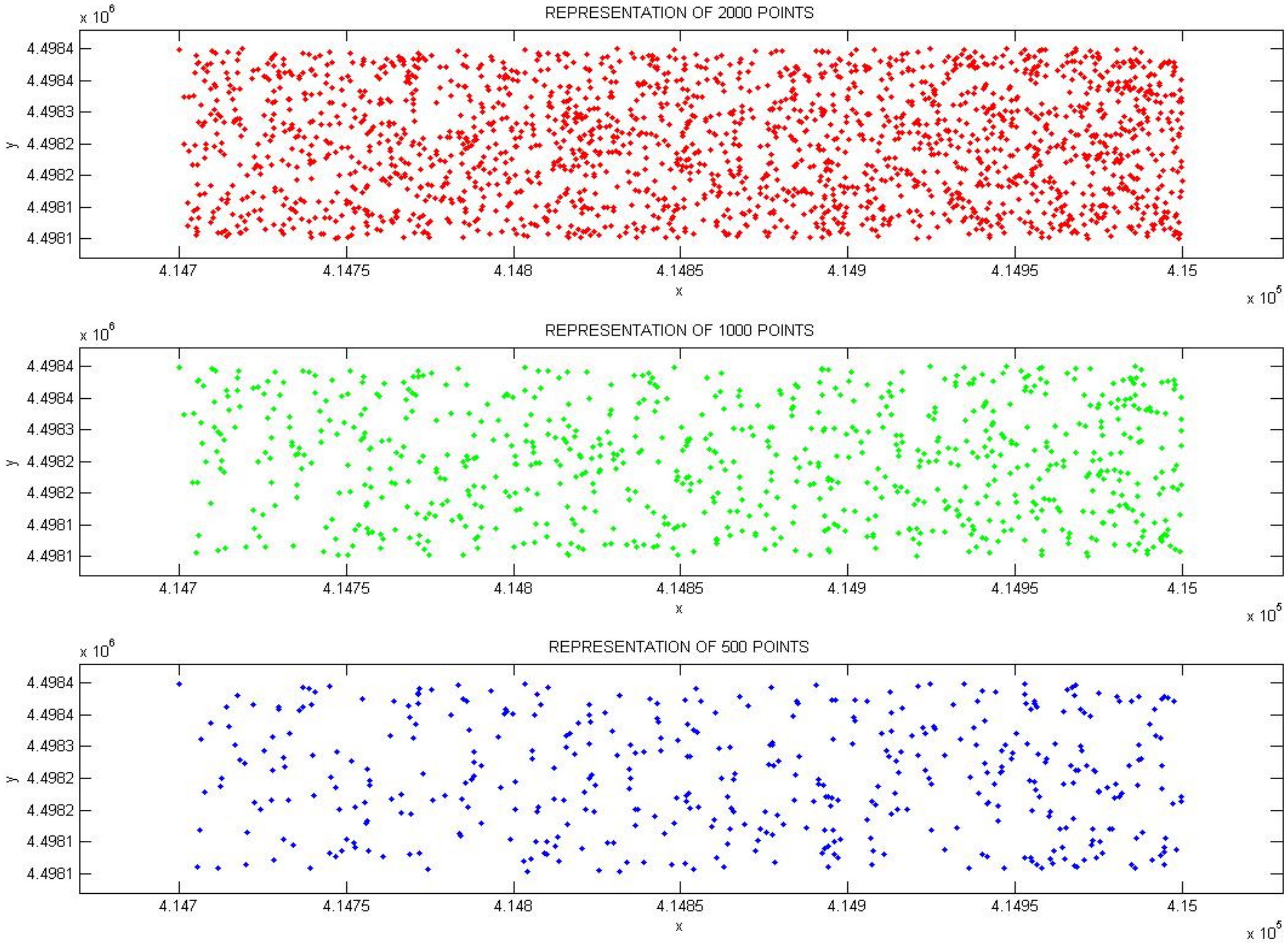
DATA REDUCTION ALGORITHM

- These random numbers are the indexes of the points we will select from the data file.

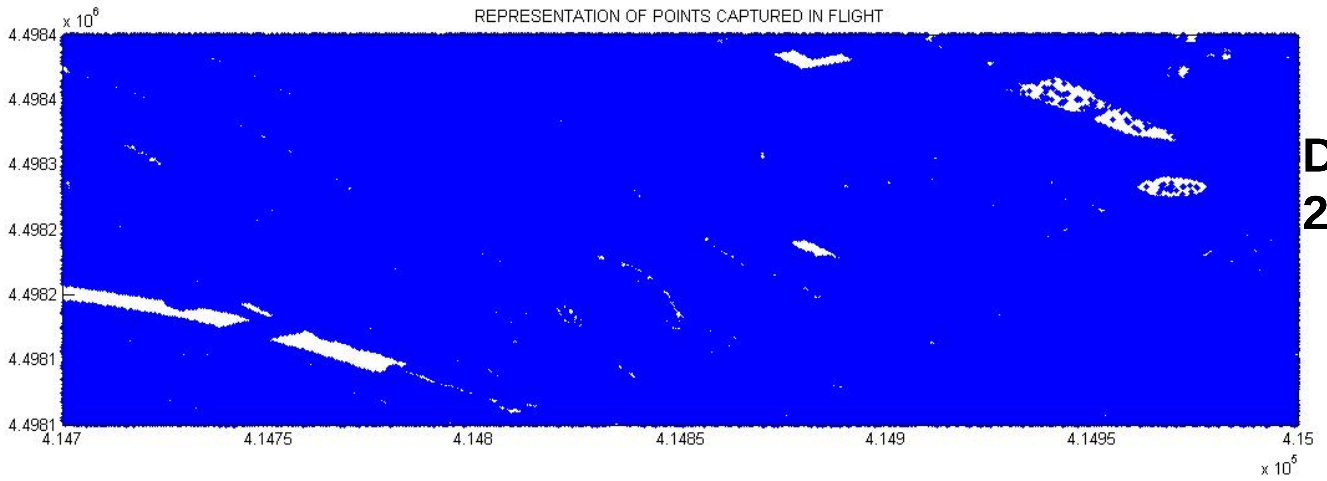
```
% extract the data with the previous indexes
datos_reduccion = datos_iniciales(ind_selec,1:3);
% save the data in a txt file
save -ascii 'datos_reduccion1.txt' datos_reduccion;
```

- This program may be used repeatedly for different reductions necessary to achieve the minimum density of points that does not exceed the tolerance given.

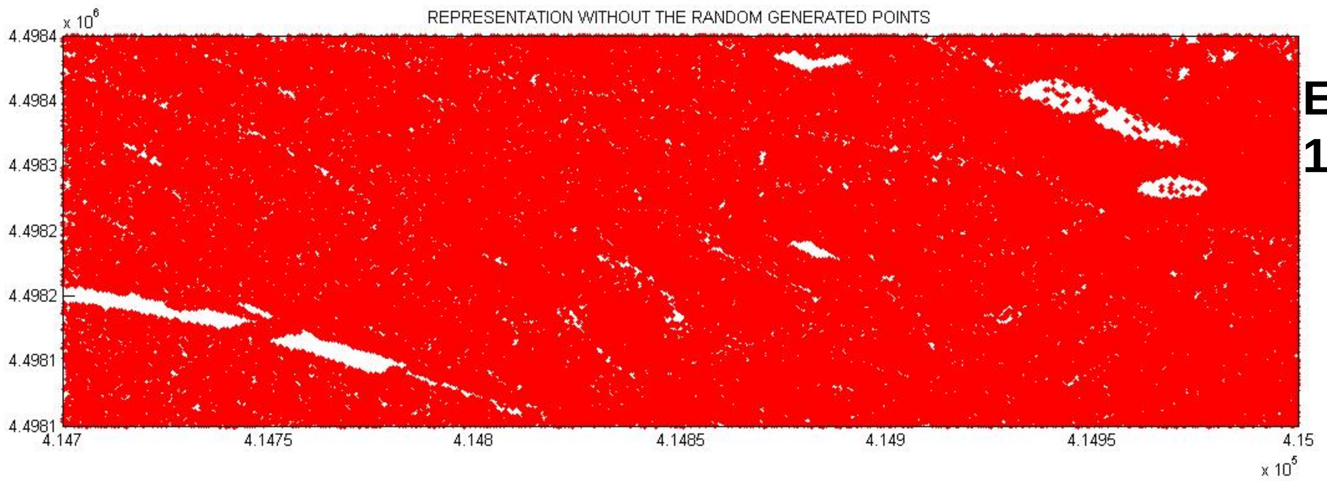
An example with 2000, 1000 and 500 points



Our problem



Data provided: 210418 points



Extracted points: 100000 points

INTERPOLATION METHOD

- Search interpolation method to construct the digital model, based on a regular mesh. To do this we use the subroutine of MATLAB ***griddata***:

  ZI = GRIDDATA(X,Y,Z,XI,YI,METHOD)

  where METHOD is one of:

  - 'linear' - Triangle-based linear interpolation (default)

  -'nearest' - Nearest neighbor interpolation

  defines the type of surface fit to the data.

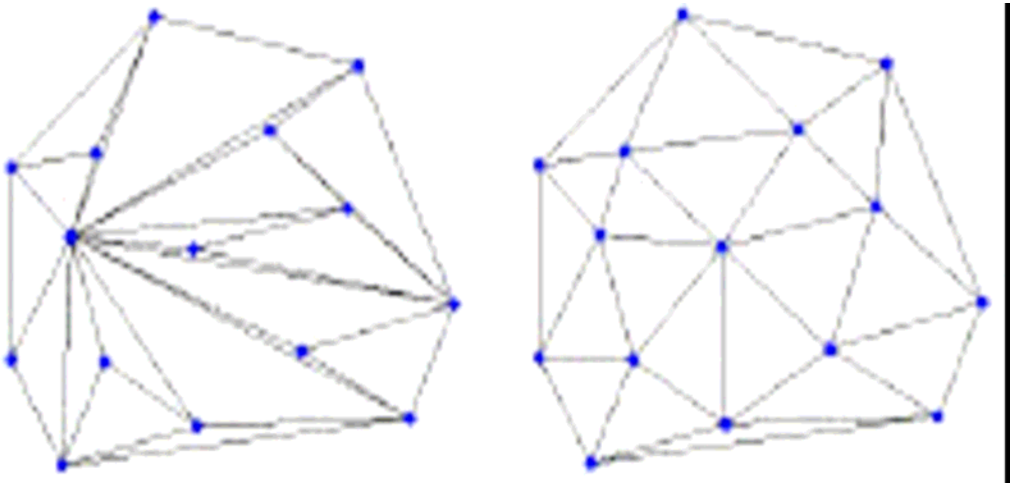
HOW DOES GRIDDATA WORK?

Those methods are based on a **Delaunay** triangulation of the data.

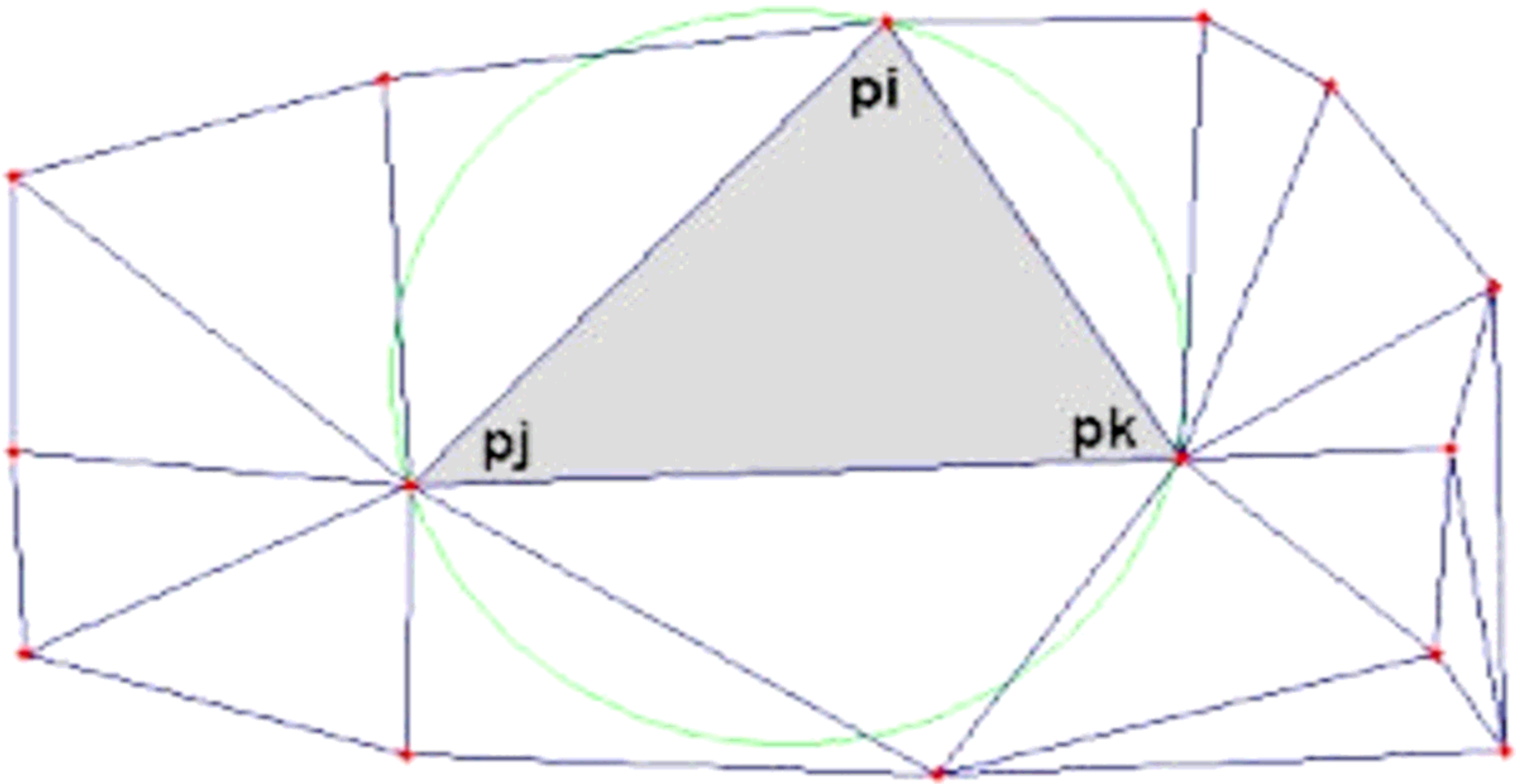
TRIANGULATION: A triangulation is a subdivision of an area in triangles.

DELAUNAY TRIANGULATION: triangulation that best approximates a terrain is the one that forms the "more regular triangles”, because it will give us a more accurate picture. In this way we arrive at the Delaunay Triangulation.

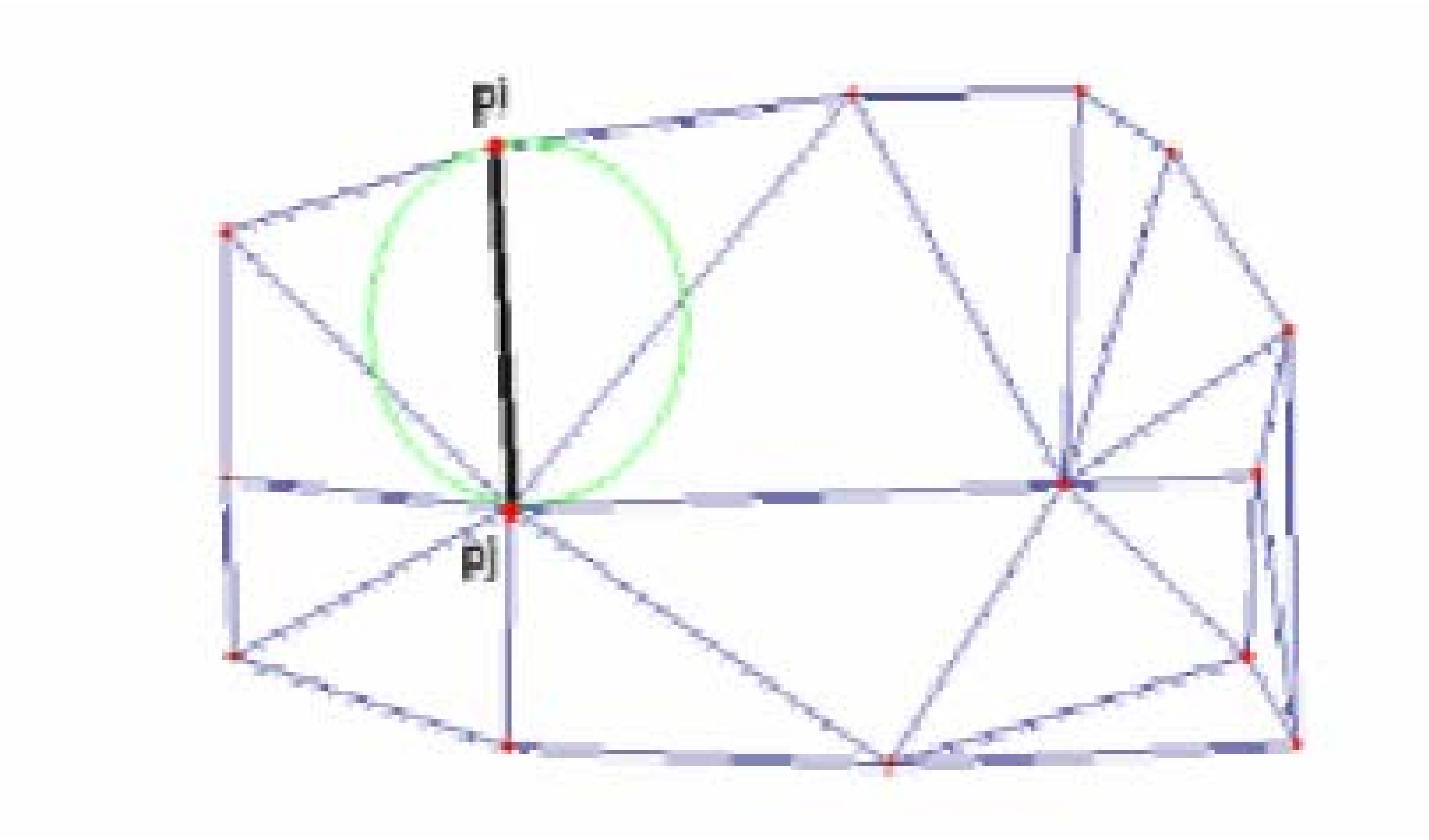
- The best one should be the triangulation with equilateral triangles; when this choice isn't possible Delaunay triangulation maximizes the minimum angle of all the angles of the triangles in the triangulation.



PROPERTY 1:



PROPERTY 2:

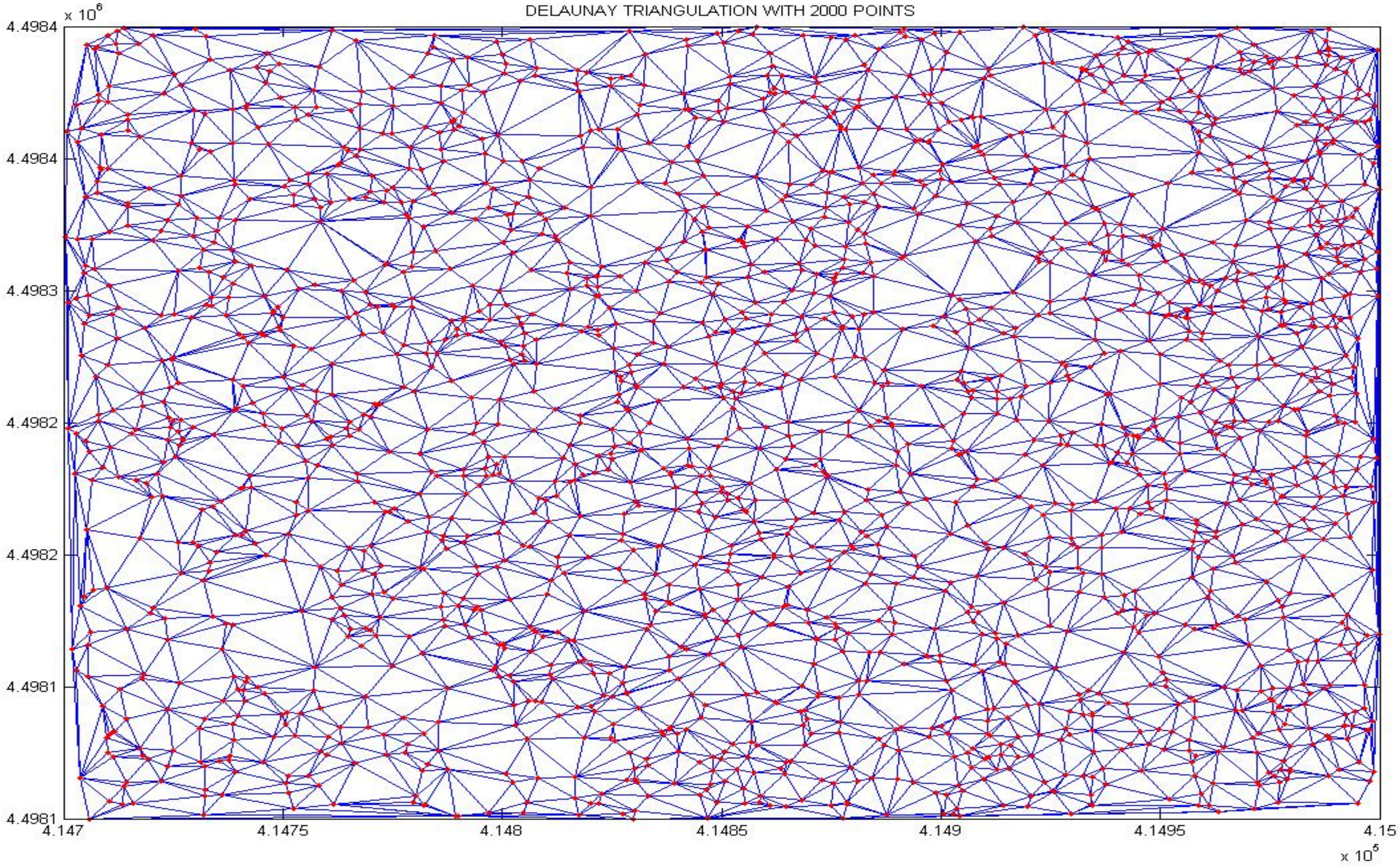


CHARACTERIZATION OF DELAUNAY TRIANGULATION

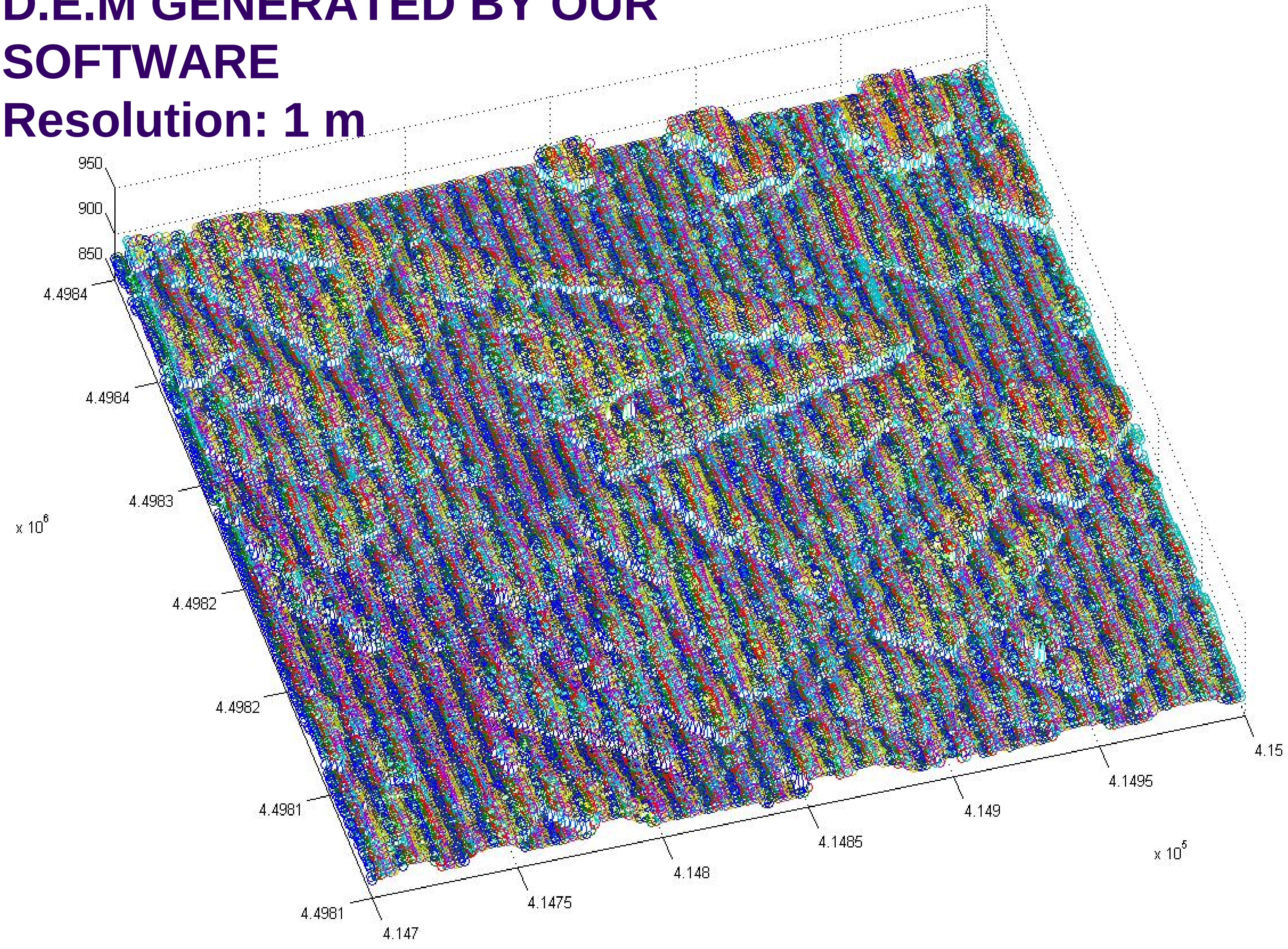
Let P be a set of points in the plane and T a triangulation of P, then T is:

a Delaunay triangulation of P, if and only if a circle circumscribing any triangle of T does not contain any other input points inside.

Delaunay Triangulation with some of our data

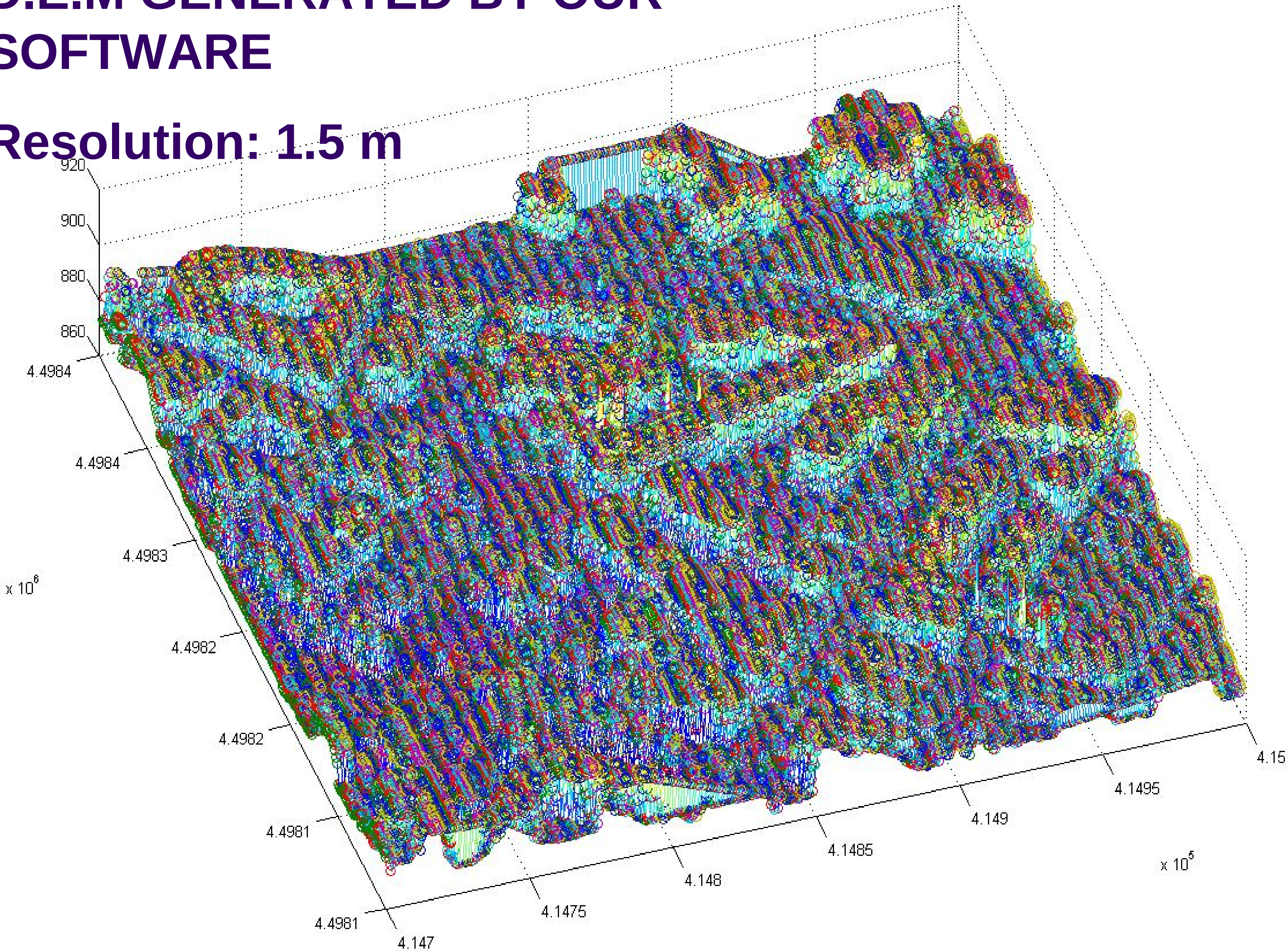


D.E.M GENERATED BY OUR SOFTWARE
Resolution: 1 m



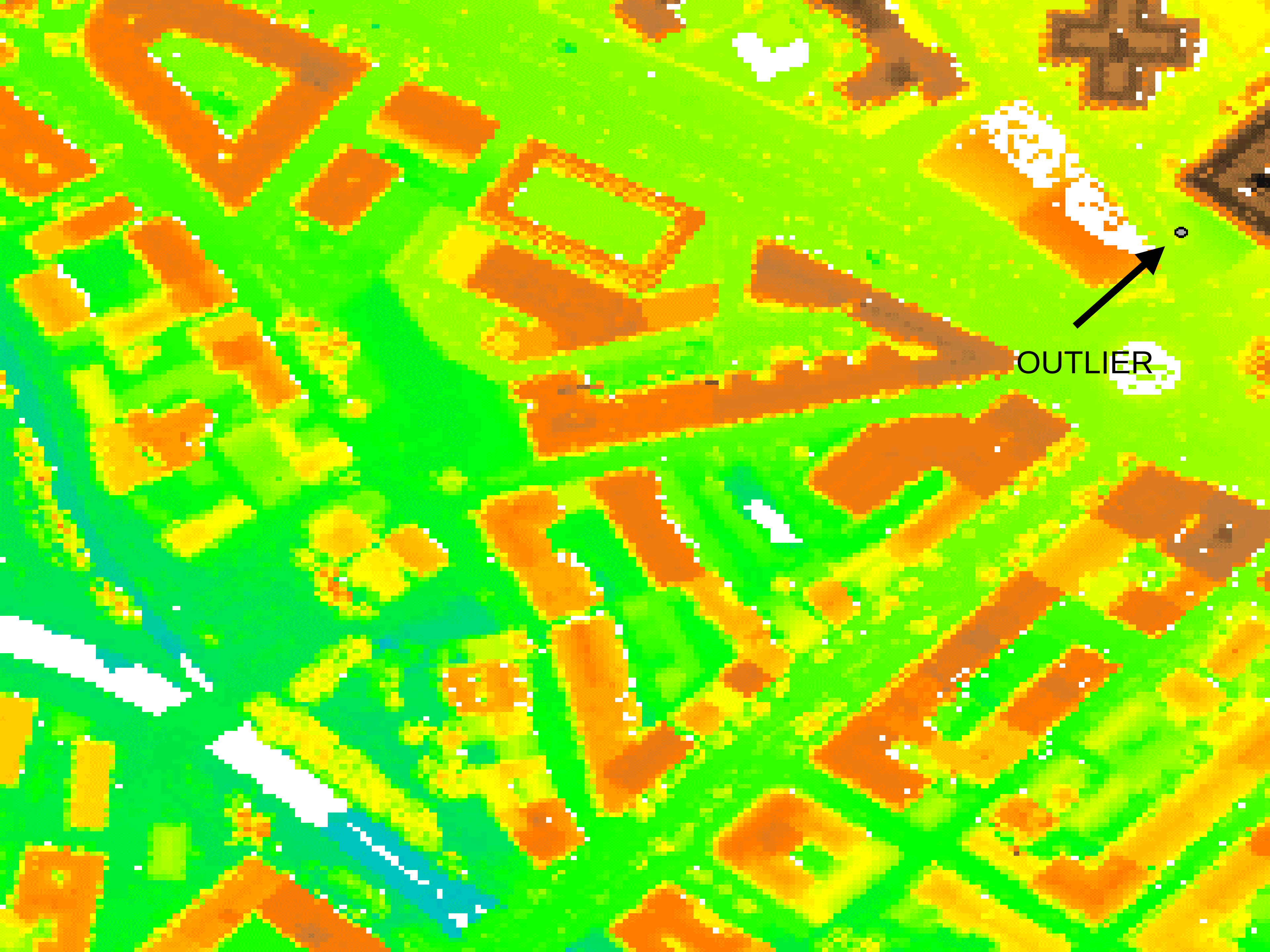
D.E.M GENERATED BY OUR SOFTWARE

Resolution: 1.5 m



NUMERICAL RESULTS

Validation test with 32 points		
DEM 1 Points/m^2	Error in the linear interpolation	Error in the nearest interpolation
Original data 210418 Data 2,35 Points/m^2 800 m Height Flight	Max 0,295 Min $1{,}13 \cdot 10^{-13}$ Aver. 0,0869 Median 0,0655 Std. Dev. 0,076	Max 0,32 Min 0 Aver. 0,072 Median 0,0655 Std. Dev. 0,081
1st Data reduction 100000 Data 1,11 Points/m^2 1300 m Height Flight	Max 0,327 Min 0 ,00055 Aver. 0,0922 Median 0,0654 Std. Dev. 0,089	Max 5’44 Min 0 Aver. 0,259 Median 0,045 Std. Dev. 0,951
2nd Data reduction 75000 Data 0,84 Points/m^2 2200 m Height Flight	Max 0,287 Min 0 ,002 Aver. 0,081 Median 0,049 Std. Dev. 0,079	Max 0,47 Min 0 Aver. 0,095 Median 0,035 Std. Dev. 0,108
3th Data reduction 70000 Data 0,78 Points/m^2 2250 m Height Flight	Max 0,226 Min 0 ,002 Aver. 0,072 Median 0,045 Std. Dev. 0,064	Max 0,3 Min 0 Aver. 0,084 Median 0,035 Std. Dev. 0,084
4th Data reduction 60000 Data 0,66 Points/m^2 2500 m Height Flight	Max 0,664 Min 0 ,001 Aver. 0,112 Median 0,073 Std. Dev. 0,131	Max 0,3 Min 0 Aver. 0,092 Median 0,03 Std. Dev. 0,091
5th Data reduction 50000 Data 0,55 Points/m^2 2700 m Height Flight		Max 0,26 Min 0 Aver. 0,078 Median 0,03 Std. Dev. 0,079
6th Data reduction 40000 Data 0,44 Points/m^2 3000 m Height Flight		Max 0,484 Min 0 Aver. 0,246 Median 0,03 Std. Dev. 0,846


OUTLIER

NUMERICAL RESULTS

Validation test with 32 points		
DEM 1.5 Points/m^2	Error in the linear interpolation	Error in the nearest interpolation
Original data 210418 Data 2,35 Points/m^2 800 m Height Flight	Max 0.455 Min 0 Aver. 0.100 Median 0.062 Std. Dev. 0.111 MSE. 0.3831	Max 0.45 Min 0 Aver. 0.99 Median 0.075 Std. Dev. 0.097 MSE. 0.29
1st Data reduction 100000 Data 1,11 Points/m^2 1300 m Height Flight	Max 0.465 Min 0.007 Aver. 0.118 Median 0.087 Std. Dev. 0.109 MSE. 0.373	Max 0.78 Min 0 Aver. 0.135 Median 0.085 Std. Dev. 0.166 MSE. 0.856
2nd Data reduction 75000 Data 0,84 Points/m^2 2200 m Height Flight	Max 0.424 Min 0.001 Aver. 0.107 Median 0.085 Std. Dev. 0.097 MSE. 0.296	Max 0.47 Min 0 Aver. 0.108 Median 0.07 Std. Dev. 0.117 MSE. 0.421
3th Data reduction 70000 Data 0,78 Points/m^2 2250 m Height Flight	Max 0.423 Min 0.006 Aver. 0.09 Median 0.076 Std. Dev. 0.094 MSE. 0.278	Max 20.5 Min 0 Aver. 0.735 Median 0.07 Std. Dev. 3.608 MSE. 403.53
4th Data reduction 50000 Data 0,55 Points/m^2 2700 m Height Flight	Max 2.575 Min 0.002 Aver. 0.191 Median 0.089 Std. Dev. 0.448 MSE. 6.226	

CONCLUSIONS

IT IS POSSIBLE TO GET THE SAME DEM REDUCING THE COST IN TERMS OF HEIGHT AND TIME OF SURVEY TO CAPTURE A SMALLER NUMBER OF POINTS

NEAREST INTERPOLATION

D.E.M resolution 1m x 1m

0.55 points/m2

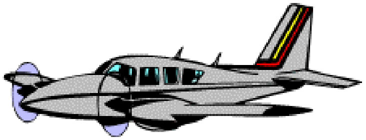
2700m

LINEAR INTERPOLATION

D.E.M resolution 1.5m x 1.5m

0.78 points/m^2

2250m



2.35 points/m^2

800 m