Digital Elevation Models (DEM) for the Analysis of the paved surface of Linear Infrastructures

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AIM

The work aims at studying and analyzing algorithms for the processing of point clouds acquired with remote sensing techniques (photogrammetry or LiDAR) in order to obtain an accurate 3-D model of the surface of linear infrastructures, which can be used to obtain reliable information on its deterioration.

A. Digital Elevation Model with curved abscissa (DEMc)

The characteristic plano-altimetric development of the road belt makes unsuitable the classic methods used for the extraction of DEM, on which are based most of the modelling softwares [1-3].

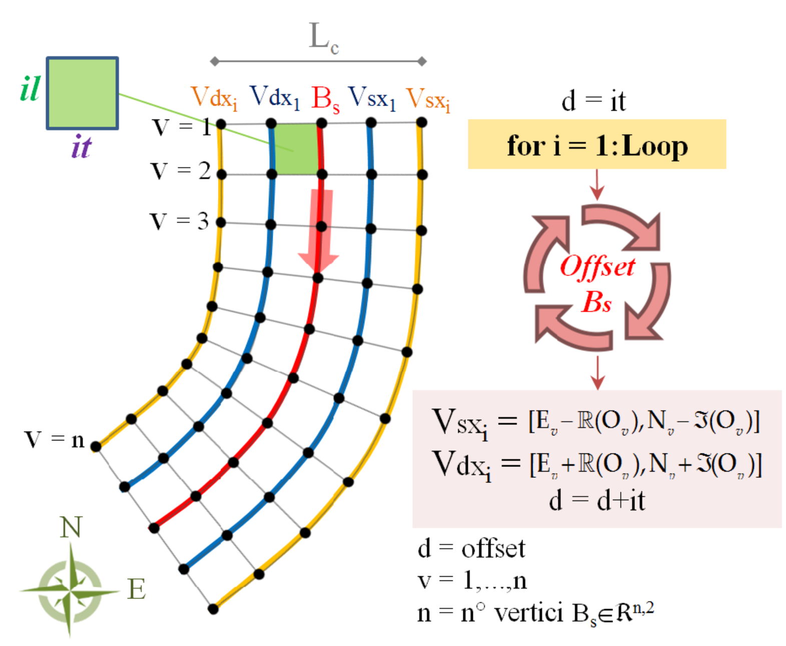
The classical methodologies reconstruct the trend of a given variable according to a regular grid of nodes starting from the measured and irregularly distributed discrete values. This is done by means of interpolation techniques with which a statistical, or deterministic, surface is modelled, usually in matrix format with a resolution chosen by the user; each element of the matrix corresponds to an elevation value.

The use of the grid DEM is mainly due to the ease with which the matrices can be treated mathematically, even in a GIS environment, without great computational cost. Nevertheless, it is clear that a grid structure oriented according to the North-South cartographic grid is not effective to represent the curvilinear development of a road belt.

We have studied a methodology to generate a grid DEM whose abscissa is curved, called DEMc, suitable for road pavements, which optimizes not only the computational cost but also the organization and the plano-altimetric analysis starting from measures acquired with Mobile Laser Scanner (MLS) [4]. The building of this model is semiautomatic; the elevation value of each single node of the grid is estimated through spatial interpolation processes specially modified and implemented in Matlab environment. The algorithm foresees a variation of the search radius according to the surface characteristics of the road and the density of the data itself.

The output file is organized so as to extract the transverse and longitudinal profiles with respect to a chosen reference system.

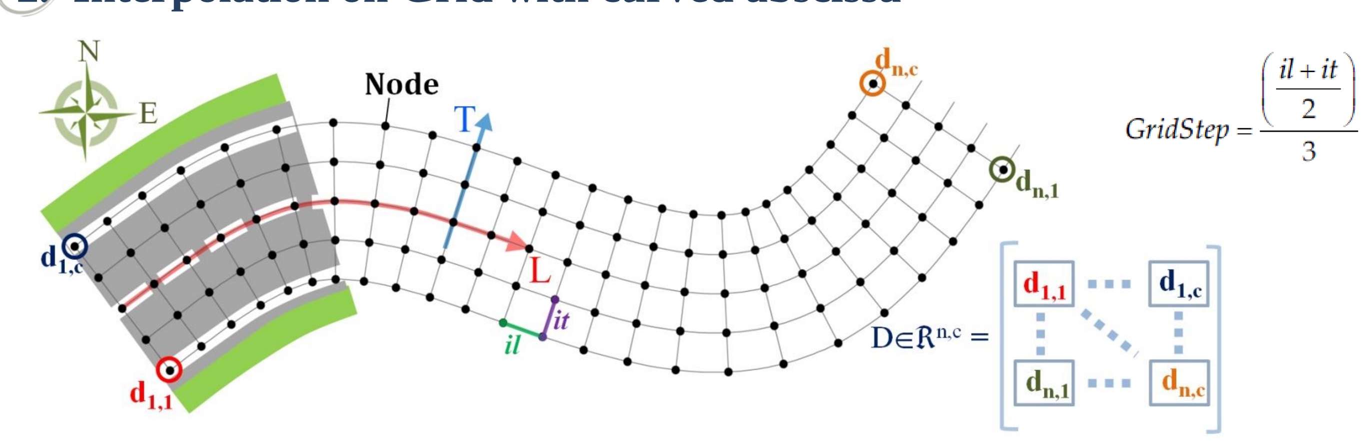
1. Offset cycle and generation of the planimetric grid



Repeated sequences of instructions generate numerous variables with the same names; for this reasons all outputs are organized in Structure Array. In particular, the planimetric coordinates of the nodes are organized in Multidimensional Arrays $D \in \mathbb{R}^{n,(2\cdot Loop+1),2}$, an extension of a two-dimensional matrix.

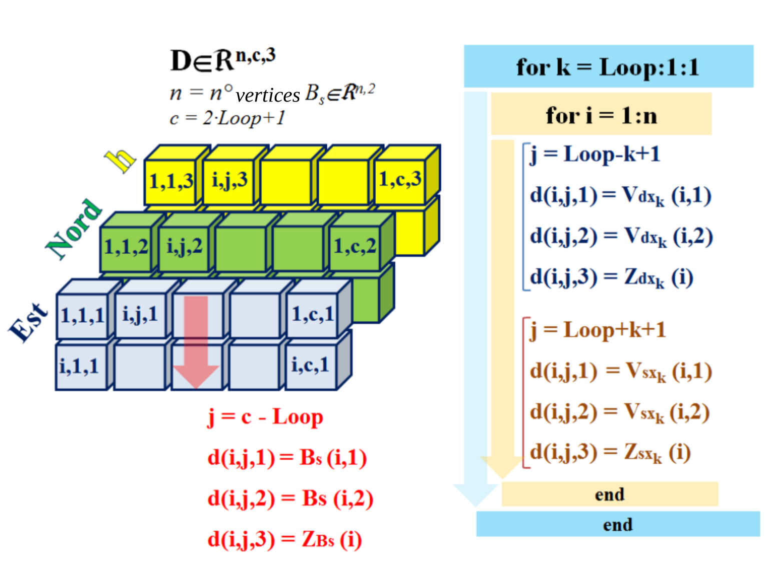
$$Loop = \frac{\left(\frac{L_c}{2}\right)}{it}$$

2. Interpolation on Grid with curved abscissa



$$GridStep = \frac{\left(\frac{il+it}{2}\right)}{3}$$

The elevation value of each single node of the two-dimensional grid is estimated by means of **spatial interpolation processes**



Criteria for the choice of the interpolation step ρ

a) Geometric

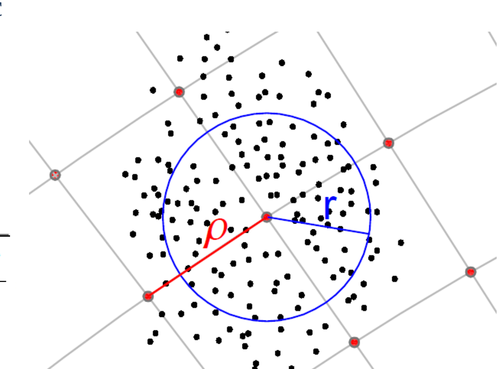
b) Dynamic

$$r = \frac{\sqrt{2}}{2} \cdot \rho$$

$$\rho = 0,5 \cdot \sqrt{\frac{1m^2}{D}}$$

ρ: il (grid step)

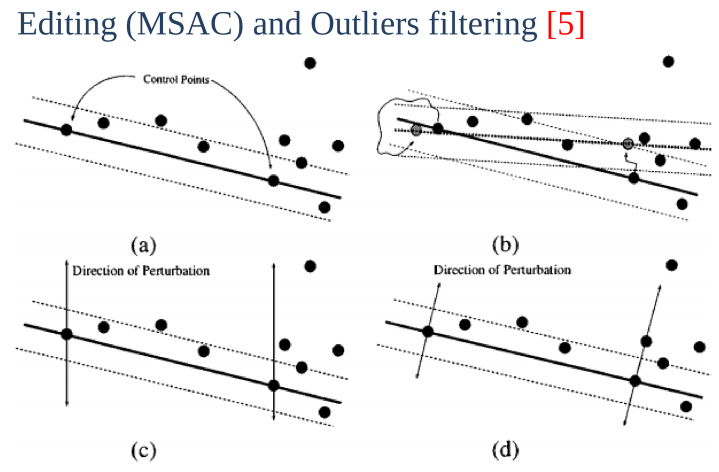
r : Search radius.



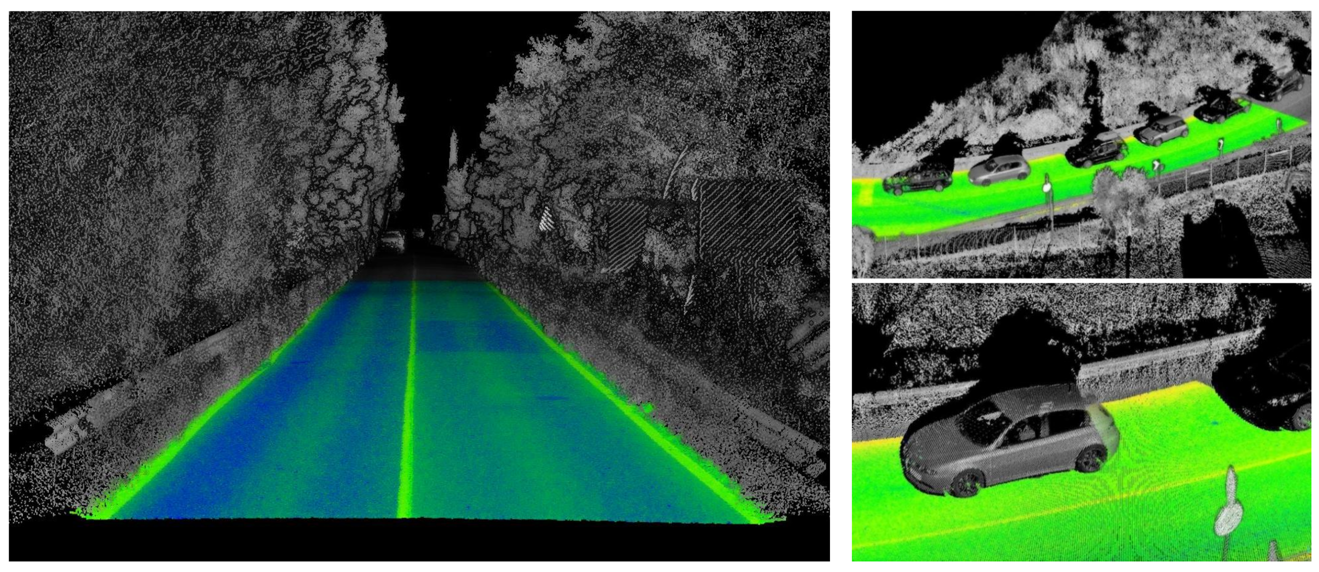
$$h_{NODO_i} = \frac{\sum_{j=1}^{nr} h_j(E_{pj}, N_{pj}) \cdot d^{-k}}{\sum_{j=1}^{nr} d^{-k}}$$

Outlier filtering

Editing (MSAC) and Outliers filtering [5]



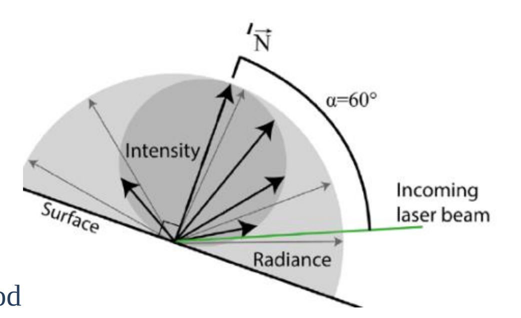
Torr, P. H. S., and A. Zisserman. "MLESAC: A New Robust Estimator with Application to Estimating Image Geometry." Computer Vision and Image Understanding. 2000.

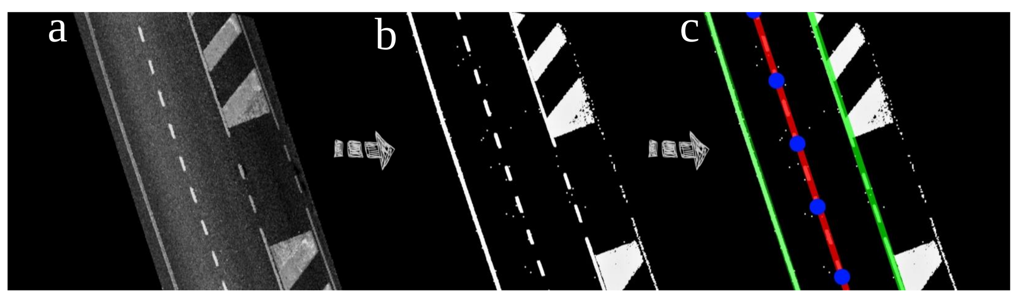


Extraction of the polyline corresponding to the axis from the road markings

The radiometric data acquired by the laser scanner are subjected to processes of:

1. Radiometric correction of intensity values
   - Distance to the scanner
   - Angle of incidence
2. Otsu segmentation



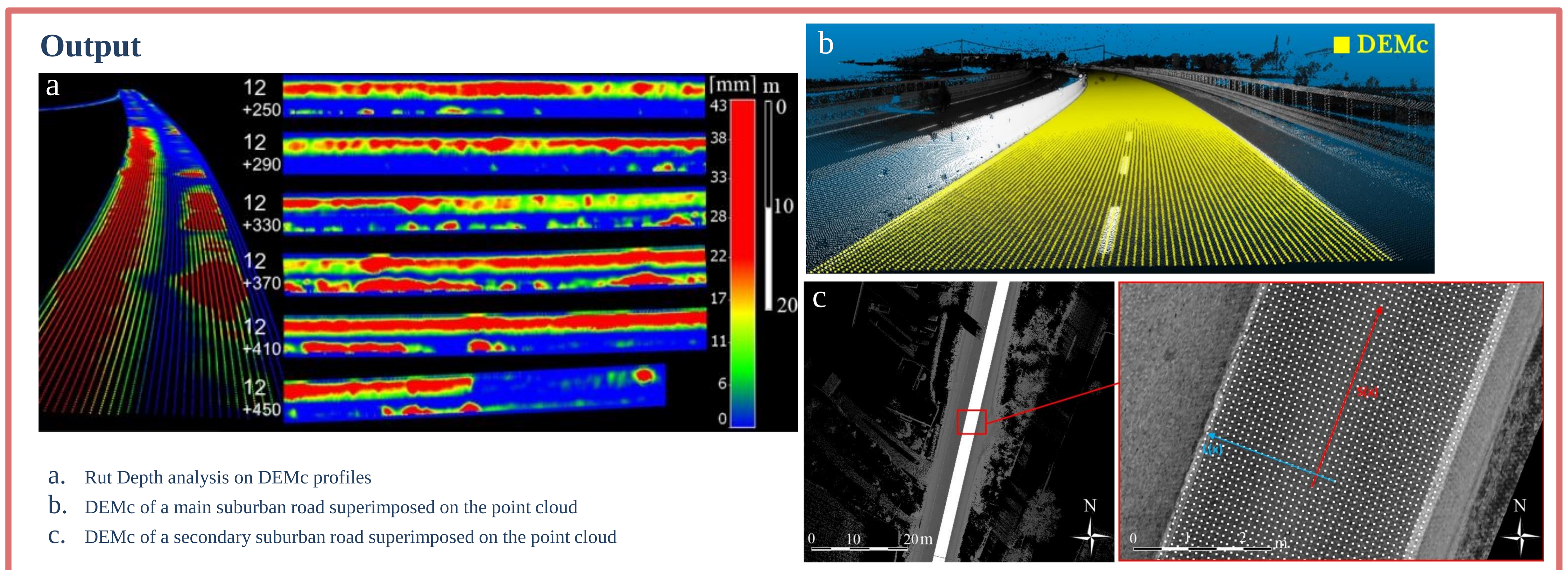


a. Data corrected radiometrically

b. Segmentation according to the Otsu method

c. Extraction of polylines (axis and edges)

Output



a. Rut Depth analysis on DEMc profiles

b. DEMc of a main suburban road superimposed on the point cloud

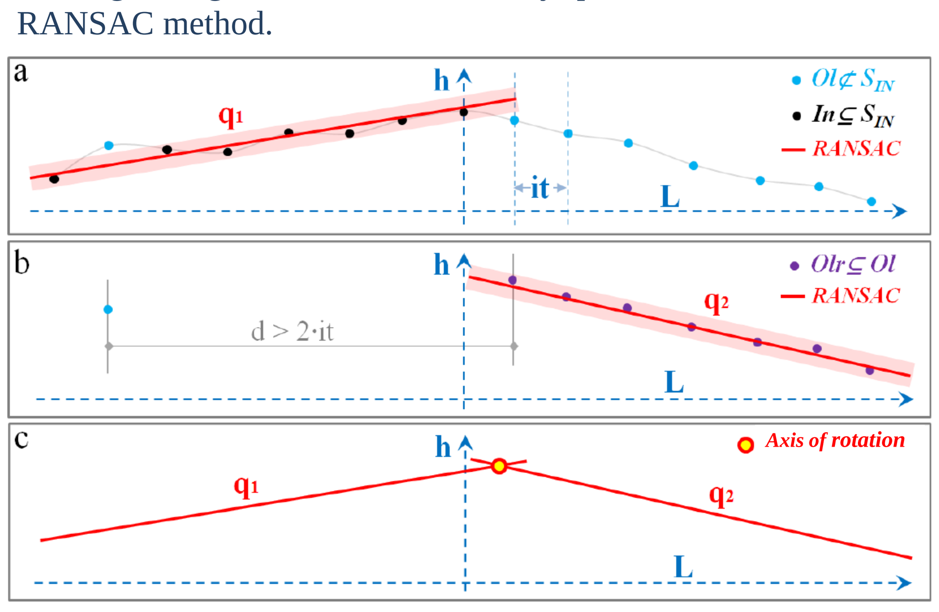
c. DEMc of a secondary suburban road superimposed on the point cloud

B. Deviation of the paved surface

A more advanced example of the digital paving model was based on the study of the deviation of the paved surface from a reference plane. The process involves the creation of a two-pitched flat surface constructed so as to lay on the real surface (theoretically, a road cross-section is represented by a double pitch to allow water flow). The building of the planes is carried out on road sections as wide as the entire carriageway and between 3 and 5 m long. To ensure that the pitch lays on the surface, an iterative algorithm has been implemented; at each iteration the algorithm excludes the points below the plane obtained by previous interpolation. In this way, in the next cycle, the new plane will be built by interpolation on the basis only of the data that were above the plane at the previous iteration; this method makes the plane orient itself according to the number of points remaining at each iterative cycle. The adjacent pitches, in the direction of travel, are built in such a way as to be mutually joined. This process has been implemented in the Matlab environment as well.

1. Ridge Line

Identification of the different sections at constant slope and forming the generic cross-section by processes based on the RANSAC method.



a. RANSAC .

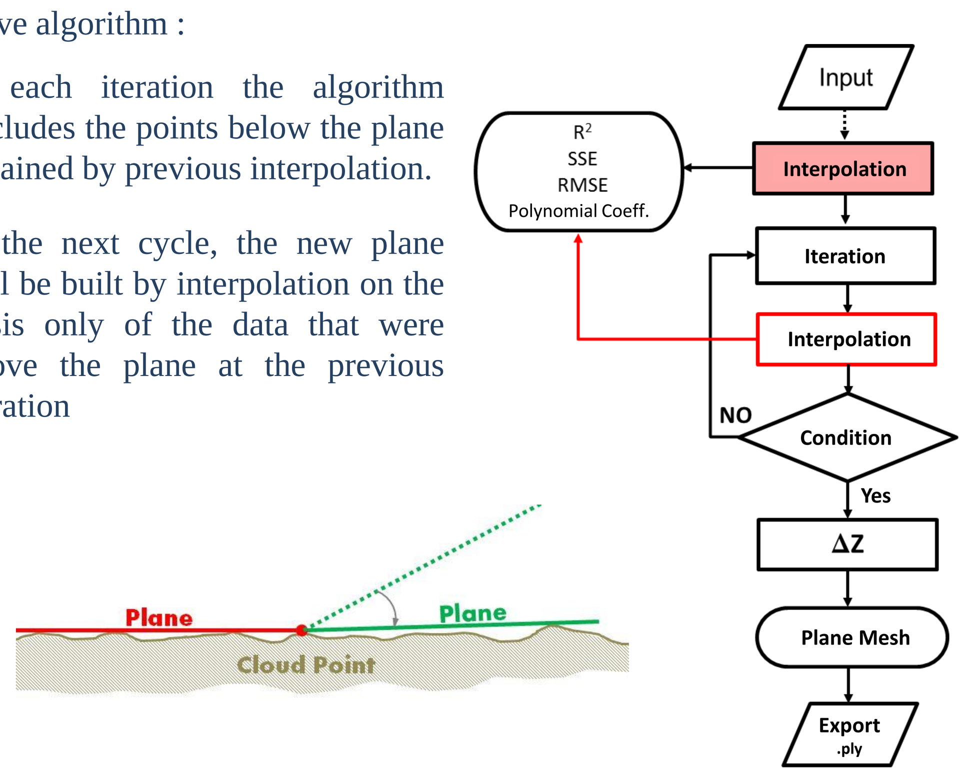
b. Verify distance Outlier.

c. Intersection of the lines and determination of the axis of rotation.

2. WorkFlow Iterative Algorithm

Iterative algorithm :

- ✓ at each iteration the algorithm excludes the points below the plane obtained by previous interpolation.
- ✓ in the next cycle, the new plane will be built by interpolation on the basis only of the data that were above the plane at the previous iteration

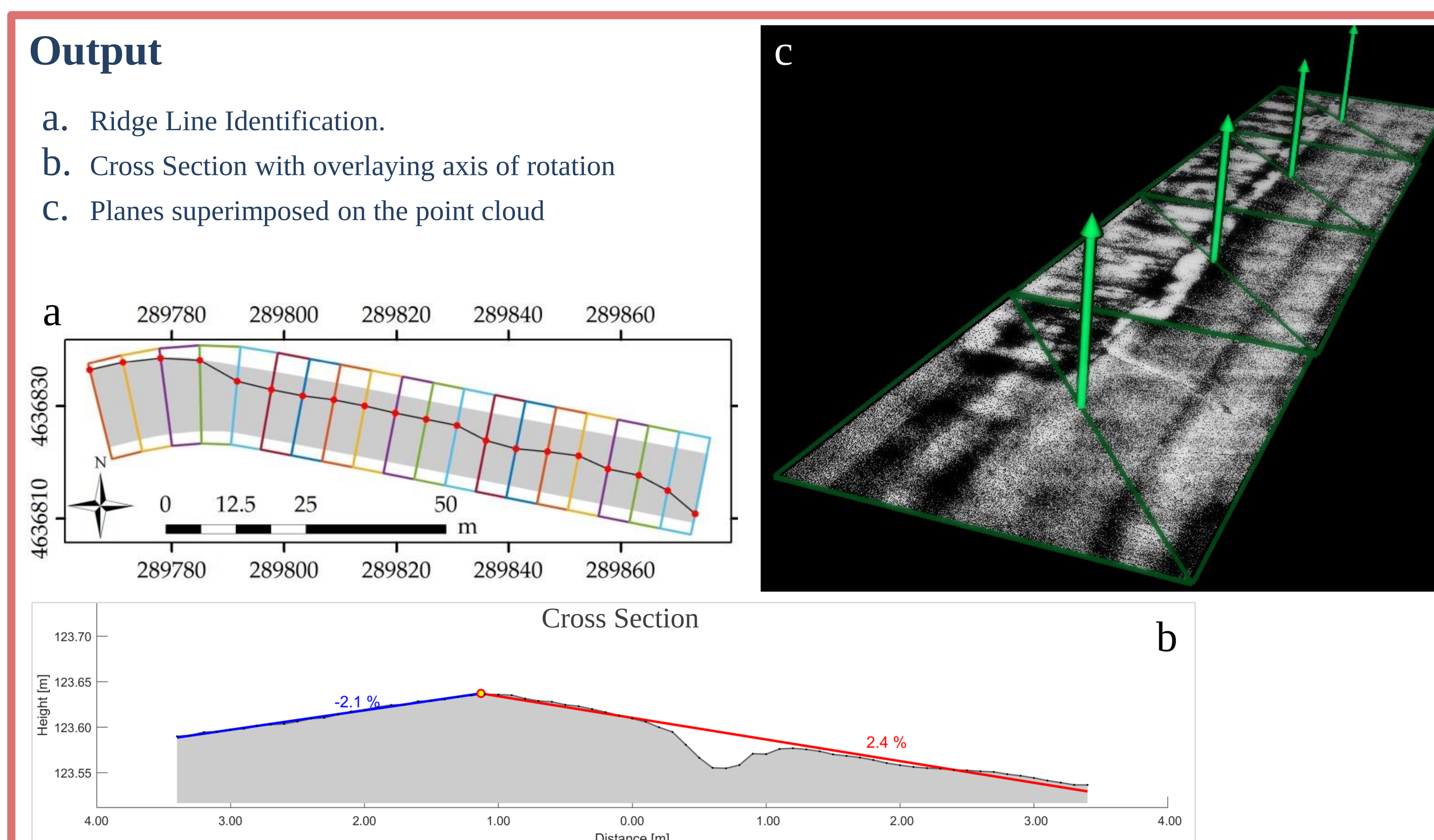


Output

a. Ridge Line Identification.

b. Cross Section with overlaying axis of rotation

c. Planes superimposed on the point cloud



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4. De Blasiis, M. R., Di Benedetto, A., Fiani, M., and Garozzo, M. "*Assessing the Effect of Pavement Distresses by Means of LiDAR Technology.*" Proc., ASCE International Conference on Computing in Civil Engineering 2019American Society of Civil Engineers.
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