Geomodels Institute of Research

Point Cloud Monitoring

Reference Guide Version 1.0 for Windows
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Introduction

Contents of Point Cloud Monitoring Reference Guide

This document contains four sections:

Presentation

The aim of this software is to give some process and analysis tools for working with cloud point in a geology environment, especially in the monitoring of rock falls. We suggest a workflow to detect and isolate clusters points from a cliff. The software is divided in four sections, the first section is to calculate planar regressions or vectorization of the monitored surface, the second section to measure differences between both surfaces, third section create clusters according the differences and finally the software create file for machine learning classification.

Software

1. Vectorization

In this section, the tool load two point cloud files to calculate a planar regression data from each point of the reference point cloud. The output files are shaped by coordinates (X, Y and Z), and his related information, constituted by the three components vector (u, v, w), Dip Direction and Dip from these vectors, parameters of: collinearity index, coplanarity index and the number of points used for each planar regression. Finally, a value relating to the intensity of the signal captured by laser scanner (Reflectivity) or the texture of the object scanned in RGB format or no information about the intensity. This menu is composing by three items.

2. Measure Differences

In this step, measure of the difference between both point clouds are measured along the vector calculated in section 2.1.

3. Clustering differences

This tool cluster points with a significative difference with respect to the reference and the compared point cloud.

4. Related documentation

Contains articles and related information where explain internal functionalities from algorithms or workflow.

- **Garcia-Sellés, D., Arbués, P., Falivene, O., Gratacos, O., Tavani, S. & Muñoz, J. A.**, (2011). *Supervised identification and reconstruction of near-planar geological surfaces from terrestrial laser scanning*. Computers & Geosciences 37, 1584–1594 (Available online in www.elsevier.com/locate/cageo).

- **Fernandez, O., 2005**. Obtaining a best fitting plane through 3D georeferenced data, Journal of Structural Geology, v. 27, pp. 855–858.

- **Woodcook, N. H.**, 1977. Specification of fabric shapes using an eigenvalue method: Geological Society of America Bulletin, v. 88, pp. 1231–1236.

Technical support

Report any problems, or send your suggestions, can be sent to Geomodels Research Institute or directly to software technical team by e-mail at *dgarcia@ub.edu*

Overview

Workflow

The software has been designed to identify changes on a surface along a time lapse (t_0-t_1) from laser scanner data with high resolution. Surface is understood as a sequence of small planes. With this aim, the software takes a cloud point (t_0) and generates multi-evaluate surfaces to recognizance planes. In a second step, along these vectors, perpendicular to the cliff surface, are measured the differences respect to a compared point cloud (t_1) to detect changes in the cliff surface and clusters of these differences are disposed. Clusters attribute (volume, area, orientation…) are calculated to characterize the event and be useful for a cluster classification (rockfall, deformation, vegetation) with machine learning techniques.

Fig. 1: Workflow figure.

Software Manual

1. Interface of the Point Cloud Monitoring software.

Software is structured in four processes, where outputs are in ASCII files. Output files visualization must be doing with software as CloudCompare, PolyWorks (Innovmetric) or similar. A root path where to automatically place the created files and a root name for the project. Processes contained in the software are:

- **Load point clouds**, load two (Reference file, t_0 and Compared file, t_1) point clouds (X, Y, Z) and Intensity (I) and/ or RGB texture corresponding to two different times of the same study of monitoring.
- **Vectorization**, to calculate a vector for each point from a planar regressions.
- **Measure differences**, for each point and along its vector is measured the distance respect to the compared closest point.
- **Clustering differences**, create cluster of point where a surface change is detected.

Each process create a ASCII log file with names, setting and time information of the process in the root folder with the following name: *PCM_log_project_name.txt*

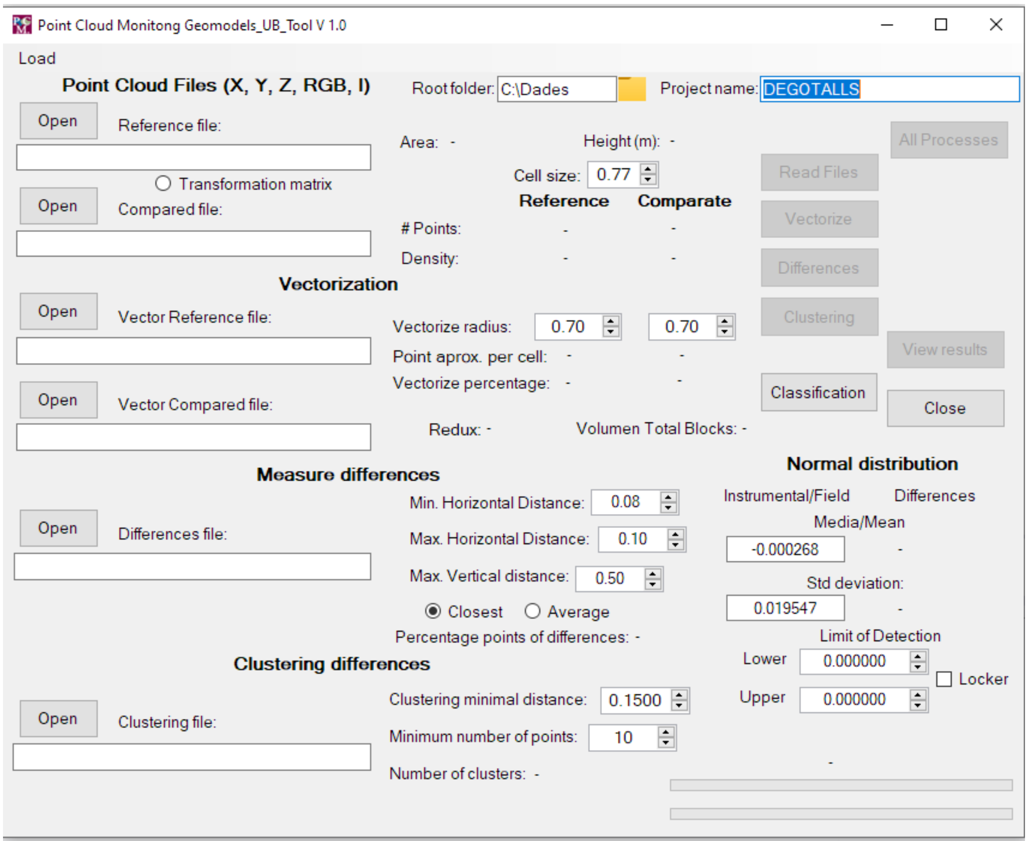


Fig. 2: Point Cloud Monitoring interface.

2. Data load

The data can be loaded from the beginning as Point clouds and complete the process step by step, creating the files for each section and completing the process. Each section can also be performed independently if the data is available in the correct format (Differences and Clustering).

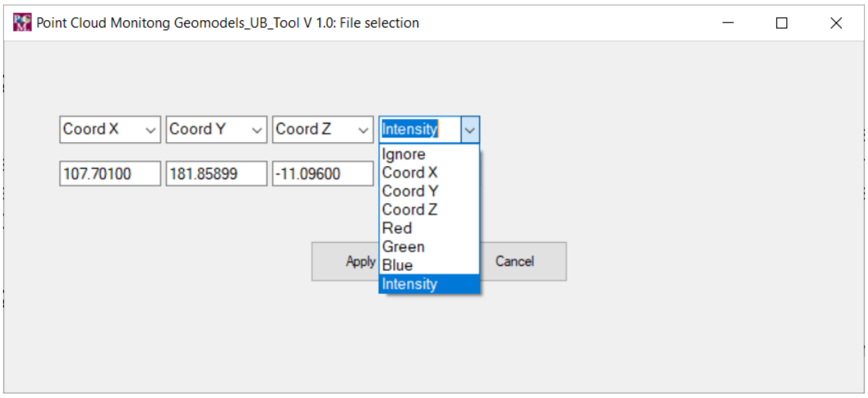


Fig. 3: Load point cloud options.

2.1 Point clouds reference and compared file format

This process load the point clouds reference and compared with 3D coordinates (X, Y, Z) without commas in ASCII code. The menu contains four options for input file attributes:

- **No texture**. Only three dimensions coordinates.
- **X Y Z + Reflectivity**. The three dimensions coordinates and laser scanner reflectivity.
- **X Y Z +R G B** The three dimensions coordinates and texture information image for red, green and blue channels.
- **X Y Z + Reflectivity + R G B** (Integer). The three dimensions coordinates and texture information of reflectivity and texture image for red, green and blue channels.

This option allow initialize the complete process (vectorization, measure differences, and clustering differences.

2.2 Vector Reference and Compared file format

The file result contains the following parameters in ASCII code.

X space Y space Z space i space j space k space Dip Dir space Dip space M space K space n + Intensity / RGB

Where each parameter means:

- **X, Y, Z**: Coordinates 3D for each point of the point cloud.
- **i, j, k**: Normal vector components calculate by the planar regression.
- **M**: Coplanarity index or Degree of fit.
- **K**: Collinearity index.
- **n**: Number of neighbouring points used to calculate each planar regression.

Options

- **Reflectivity**: 8 bytes values of intensity surveyed by laser scanner.
- **R G B**: Three values in 8 bytes to represent the texture colour of the point cloud.

2.3 Differences file Point clouds

This file in ASCII code contains 45 parameters resulting after apply the measure differences process.

Header: Scene dimensionality parameters.

1	Width axis X
2	Width axis y
3	Width axis z
4	Cell-size
5	Redux
6	Coordinate X maximal
7	Coordinate X minimal
8	Coordinate Y maximal
9	Coordinate Y minimal
10	Coordinate Z maximal
11	Coordinate Z minimal
12	Number of Reference points
13	Number of Compared points

Data:

• **n**	Reference point index
• **m**	Compared point index
• **cX(n)**	
• **cY(n)**	Point reference coordinates
• **cZ(n)**	
• **Code_n**	Reference index texture (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
• **R(n)**	
• **G(n)**	
• **B(n)**	Texture reference points
• **Intensity(n)**	
• **Vector_i(n)**	
• **Vector_j(n)**	Reference vector components
• **Vector_k(n)**	
• **Orientation(n)**	Reference vector orientation (degree)

- **Dip(n)** Reference vector slope (degree)
- **Collinearity(n)** Index
- **Coplanarity(n)** Index
- **Selected(n)** Number of used points to vectorize
- **Distance** Distance selected between closest and average
- **Vertical Distance** Vertical distance along vector with sense (+ or -)
- **Horizontal Distance** Horizontal distance component between points
- **Distance closest** Shorter distance between Refer. and Comp.point
- **cX(m)**
- **cY(m)** Point compared coordinates
- **cZ(m)**
- **Code_m** Compared index texture (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
- **R(m)**
- **G(m)**
- **B(m)** Texture compared points
- **Intensity(m)**
- **vector_i(m)**
- **vector_j(m)** Compared vector components
- **vector_k(m)**
- **Orientation (m)** Compared vector orientation (degree)
- **Dip(m)** Compared vector slope (degree)
- **Collinearity (m)** Index
- **Coplanarity (m)** Index
- **Selected (m)** Number of selected points
- **Angle** Angle between Ref. and Comp. vectors
- **Angle_Sense** Angle with sense
- **Minimal_distance** Shortest distance between those inscribed in the geometric figure
- **Average_distance** Average distance between those inscribed in the geometric figure
- **Maxima_distance** Longest distance between those inscribed in the geometric figure
- **Dev. Stand_distance** Dev.Stand distance between those inscribed in the geometric figure
- **Selected points** Number of points inscribed in the geometric figure

2.4 Clustering file

This file contains points that belong to clusters according to the difference parameters selected:

- **Code_n** Reference index texture (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
- **Code_m** Reference index texture (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
- **cXn**
- **cYn** Coordinate Reference point
- **cZn**
- **Vector_i(n)**
- **Vector_j(n)** Reference vector components
- **Vector_k(n)**
- **Orientation(n)** Reference vector orientation (degree)
- **Dip(n)** Compared vector slope (degree)
- **Colinearity (n)** Index
- **Coplanarity (n)** Index
- **R(n)**
- **G(n)**
- **B(n)** Texture reference points

- **Intensity(n)**
- **Reference point Index** Point Reference number
- **Compared point Index** Selected point Compared number
- **cXm**
- **cYm** Coordinate selected compared point
- **cYm**
- **Vector_i(m)**
- **Vector_j(m)** Compared vector components
- **Vector_k(m)**
- **Orientation(m)** Compared vector orientation (degree)
- **Dip(m)** Compared vector slope (degree)
- **Collinearity (m)** Index
- **Coplanarity (m)** Index
- **R(n)**
- **G(n)**
- **B(n)** Texture compared points
- **Intensity(n)**
- **Predominance** Index (0 Noise, 1 Advance, 2 Rock fall)
- **Predominance_0** Percentage of Predominance_0 Points (%)
- **Predominance_1** Percentage of Predominance_1 Points (%)
- **Predominance_2** Percentage of Predominance_2 Points (%)
- **Difference** Value selected distance option (Closest/Average)
- **Difference_Average** Average distance between Reference and compared cluster
- **Difference_Standart_Dev** Dev.Stand distance between Reference and Comp. cluster
- **Selected** Number of selected points
- **Closest Point** Shorter distance between Refer and Comp points
- **Distance** Final vector distance between Refer. and Comp. point
- **Horizontal distance** Horizontal distance between Refer. and Comp. point
- **Distance** Difference used (m)
- **Selected points** Number of points used
- **Angle** Angle between Ref. and Comp. vectors
- **Angle_Sense** Angle with sense
- **Minimal_distance** Shortest distance between those inscribed in the geometric figure
- **Averange_distance** Average distance between those inscribed in the geometric figure
- **Maxima_distance** Longest distance between those inscribed in the geometric figure
- **Dev. Stand_distance** Dev.Stand distance between those inscribed in the geometric figure
- **Selected points** Number of points inscribed in the geometric figure

3. Setting options

PCM software requires a configuration according to the dimensions of the scenario and the density of the point cloud:

Cell size (m): This parameter defines the size of the box where the points are referenced in order to facilitate their access by the algorithms. These three-dimensional boxes occupy the entire volume of the study area. It is recommended, due to its efficiency, that it be slightly higher than the vectorization radius

Vectorize radius (m): This distance control the search radius of points around a point to calculate the normal vector to the plane defined by them.

4. Vectorization

Each point of the reference and compared point cloud is vectorized with the small surface defined by their neighbouring points. The neighbouring points are defined by the distance selected with the "*Vectorize radius*" distance. This small cluster of points is considered as an approximation to a surface where calculate a normal vector.

The interpolation to calculate the normal vector is based on the eigenvector method using the moment of inertia analysis that allows calculating the plane orientation and indices of collinearity and coplanarity (Woodcook, 1977; Fernández, 2005). The resultant parameters are:

Vector components (I, j, k): Normal vector components calculate by the planar regression.

Coplanarity index: or degree of fit. Good planes have higher index values. Value 3.2 is an acceptable value for good planes. We must decide cut value to separate accepted planes from rejected planes. If we want keep open the threshold, put zero. Upper accepted limit is 500. We can define the cut value in other process.

Collinearity index: Collinearity index. Good planes have lower values. An acceptable threshold may be 0.8 or 1.2. Open value is 100. In this case, value can be defined in other process.

n: Number of points used to calculate each planar regression.

Options

Reflectivity: 8 bytes values of intensity surveyed by laser scanner.

R G B: Three values in 8 bytes to represent the texture colour of the point cloud.

The result files are called:

PCM_1_Project_name_Vector_Refer.txt

PCM_2_Project_name_Vector_Compared.txt

5. Measure distance

The measure of the differences between the reference (t_0) and compared (t_1) point cloud are made along the direction defined by the normal vector. The algorithm search the closest compared point into the geometrical figure of a double truncated cone defined by three parameters.

Maximal horizontal distance (m): In the top of the vertical distance

Minimal horizontal distance (m): In the base or position of the reference point

Vertical distance (m): Maximum vertical distance for the search of the compared point along the normal direction of the vector.

Closest point / Average: This option allows you to select one of the two to measure the difference between the reference point cloud and the compared one. Select the closest point to the reference point vector of the compared point cloud or reference the average distance calculated with the points inscribed by the double truncated cone.

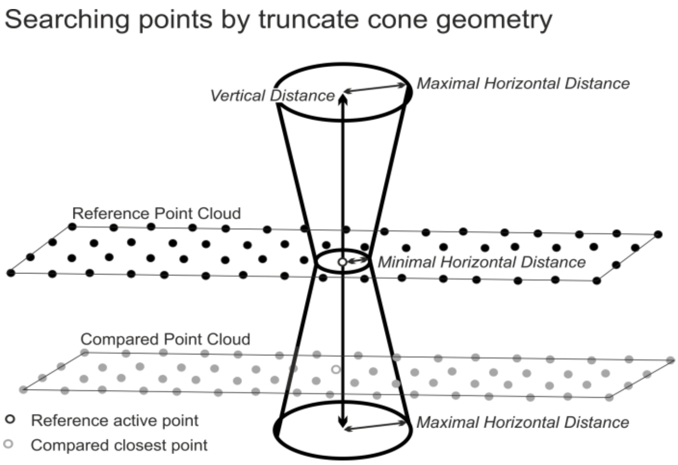


Fig. 4: Scheme of the double truncate conus for searching points.

The created file contains for each reference point, the attributes generated during its vectorization, the compared point chosen by the algorithm for measure changes, its vectorization attributes and eleven parameters associated with the measurement distance and the relationship between the reference and comparison vectors. The file also includes 13 items (section 2.3) in the header relative to the size of the study area.

- **Distance** Distance between compared and reference points
- **Vertical Distance** Vertical distance along vector with sense (+ or -)
- **Horizontal Distance** Horizontal distance component between points
- **Distance** Distance between compared and reference points

- **Angle** Angle between Ref. and Comp. vectors
- **Angle_Sense** Angle with sense
- **Minimal_distance** Shorter distance
- **Averange_distance** Statistical distance of measured points
- **Maxima_distance** Longer distance
- **Dev. Stand_distance** Statistical distance of measured points
- **Selected points** Number of points into the searching parameters

6. Clustering

In this third process, each point is classified according to its Limit of Detection (LoD) and analysed the surrounding Lods. The classification attend to if the difference of each point is noise or if belong to an advance event or retreat.

The result of this process is the file:

PCM_4_Project_Name_Clustering.txt

And the new parameters are:

- **Predominance** Index (0 Noise, 1 Advance, 2 Rock fall)
- **Predominance_0** Percentage of Predominance_0 Points (%)
- **Predominance_1** Percentage of Predominance_1 Points (%)
- **Predominance_2** Percentage of Predominance_2 Points (%)

6.1 How define the Limit of Detection (LoD)

The detection limit can be defined by the user by filling in the field. If the monitoring system is calibrated, i.e., the LoD is known according to the specifications of the point cloud capture technique for the distance and material to be studied, this field can be filled in directly.

One way to calibrate the system is to create two point clouds of the scenario to be studied in the shortest possible time and calculate the differences. The differences are assumed to be non-existent and therefore, any difference recorded will be given by the error of the capture-distance-material system studied. The average of the error and its distribution defined by the mean and the standard deviation will indicate the error of the system. In a later monitoring, the registered differences higher than the system error will indicate real changes.

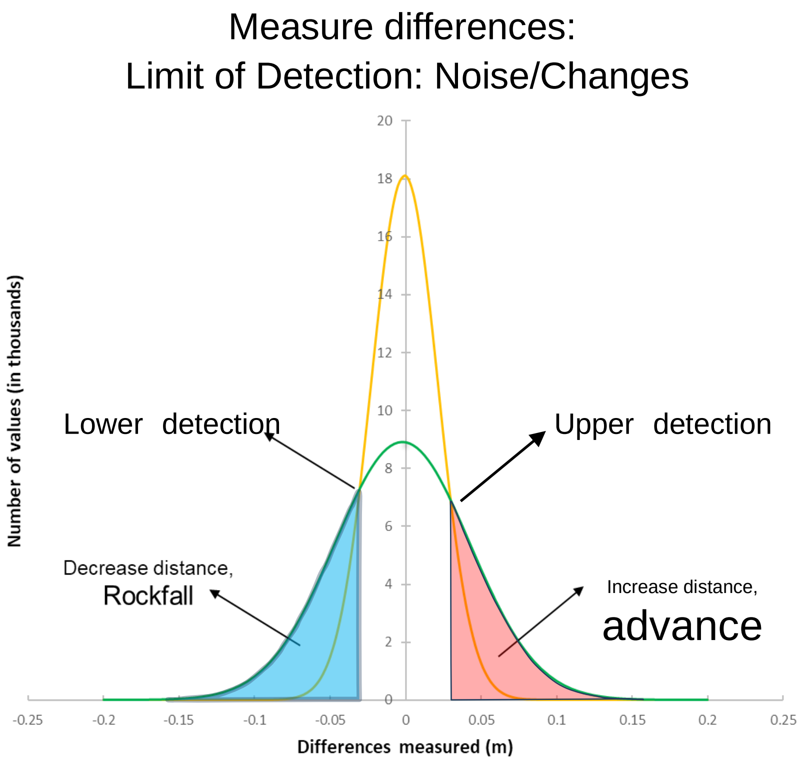


Fig. 5: Graphic for the LoD.

If the LoD is not locked, PCM compare the normal distribution of differences between the instrumental/field distribution with the measured between the Reference-Compared point clouds to calculate automatically the LoD.

6.2 Cluster creation

Finally, points are grouped by the conditions defined by the user. In the interface, the number of clusters created is visualized. New configurations can be created with the same clustering setting.

Clustering minimal distance (m): Starting from an initial point, the algorithm searches for surrounding points and checks the distance, accepting those that meet this requirement.

Minimum number of points (m): To be classified as a cluster, a minimum number of points can be established to define some object.

Limit of detection (m): The user can choose the limits to identify a distance as a change in the surface. It is used to differentiate differences from instrumental noise.

The results of this process are the files:

PCM_5_Project_Name_Export.txt: This file can be imported in Cloud Compare to visualize the results with the following attributes in the header.

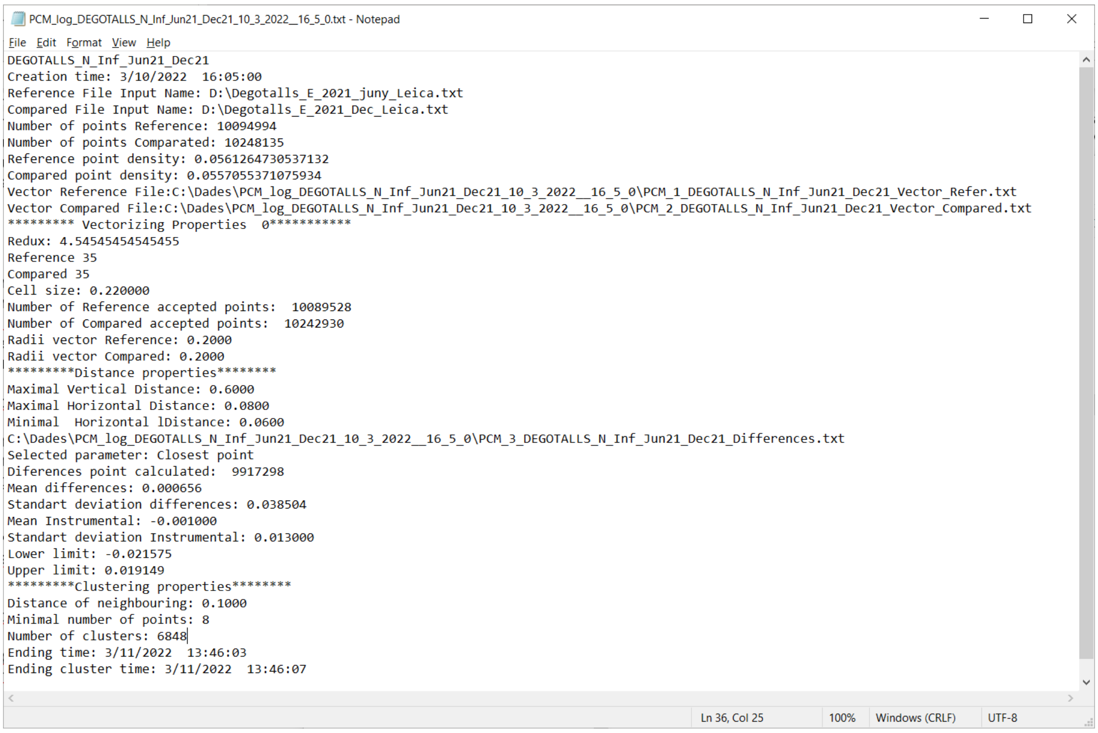
- **X**
- **Y** Point, coordinates
- **Z**
- **Cluster_Number** Cluster, number of cluster
- **Positive_Vol** Cluster, volume of the positive side (surface-device)
- **Negative_Vol** Cluster, volume of the negative side (rear surface-surface)
- **Total_Volume** Cluster, balanced volume
- **Predominium** Cluster, the predominium of the difference classification
- **Predominium_0** Cluster, the percentage of classified as noise points
- **Predominium_1** Cluster, the percentage of classified as advanced points
- **Predominium_2** Cluster, the percentage of classified as retreat points
- **Azimuth** Point vector orientation
- **Dip** Point vector dip
- **Pred_Point** Point, the predominium of the surrounding points
- **Pred_Point_0** Point, noise percentage predominium of the surrounding points
- **Pred_Point_1** Point, advanced percentage predominium of the surrounding points
- **Pred_Point_2** Point, retreat percentage predominium of the surrounding points
- **Distance** Point, distance between reference and compared point
- **Distance_Points** Point, distance sense between reference and compared point
- **CoefCorrelacion** Cluster, degree of sphericity of the cluster

PCM_6_Project_Name_Cluster.txt: This file contains the cluster parameters used to classify cluster with the *Cluster_Classification* python script.

- **Cx**
- **Cy** Point, coordinates
- **Cz**
- **Points cluster** Number of points that constitute the cluster
- **NumberCluster** Cluster number ordre
- **TotalVolume** Summation between negative and positive volumes
- **PositiveVol** Positive volume. Sistem Reference-surface
- **NegativeVol** Negative volume. Sistem behind surface-surface
- **Area** 2D area surface cluster projected over surface
- **Code classification** Cluster classification (Candidate, Vegetation, Limit effect)
- **Confidence** Classification confidence index
- **Predo_1_Mean** Predominace average points (0 noise, 1advance, 2 retreat)
- **Predo_1_Sigma** Predominace standard deviation
- **Predo_2_Mean** Predominace noise average points
- **Predo_2_Sigma** Predominace noise standard deviation
- **Predo_3_Mean** Predominace advance average points
- **Predo_3_Sigma** Predominace advance standard deviation
- **Predo_4_Mean** Predominace retreat average points
- **Predo_4_Sigma** Predominace retreat standard deviation
- **OrientationSetsRef** Vector reference clusters
- **OrientationSetsCom** Vector compared clusters
- **Texture Reference code** Index texture Reference (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
- **Rrmean** Red values Reference average
- **RrSigma** Red values Reference standard deviation
- **Grmean** Green values Reference average
- **GrSigma** Green values Reference standard deviation
- **Brmean** Blue values Reference average
- **BrSigma** Blue values Reference standard deviation
- **IrMean** Intensity values Reference average
- **IrSigma** Intensity values Reference standard deviation
- **Texture Compared code** Index texture Compared (0 n/a, 1 Intensity, 2 RGB, 3 RGB+Int)
- **Rcmean** Red values Compared average
- **RcSigma** Red values Compared standard deviation
- **Gcmean** Green values Compared average
- **GcSigma** Green values Compared standard deviation
- **Bcmean** Blue values Compared average
- **BcSigma** Blue values Compared standard deviation
- **IcMean** Intensity values Compared standard deviation
- **IcSigma** Intensity values Compared standard deviation
- **Path File Reference**
- **Path File Compared**

the complete history of the process is recorded with the ASCII file:

PCM_log_Project_Name.txt



PCM_log_DEGOTALLS_N_Inf_Jun21_Dec21_10_3_2022__16_5_0.txt - Notepad

File Edit Format View Help

```
DEGOTALLS_N_Inf_Jun21_Dec21
Creation time: 3/10/2022  16:05:00
Reference File Input Name: D:\Degotalls_E_2021_juny_Leica.txt
Compared File Input Name: D:\Degotalls_E_2021_Dec_Leica.txt
Number of points Reference: 10094994
Number of points Comparated: 10248135
Reference point density: 0.0561264730537132
Compared point density: 0.0557055371075934
Vector Reference File:C:\Dades\PCM_log_DEGOTALLS_N_Inf_Jun21_Dec21_10_3_2022__16_5_0\PCM_1_DEGOTALLS_N_Inf_Jun21_Dec21_Vector_Refer.txt
Vector Compared File:C:\Dades\PCM_log_DEGOTALLS_N_Inf_Jun21_Dec21_10_3_2022__16_5_0\PCM_2_DEGOTALLS_N_Inf_Jun21_Dec21_Vector_Compared.txt
********* Vectorizing Properties  0***********
Redux: 4.54545454545455
Reference 35
Compared 35
Cell size: 0.220000
Number of Reference accepted points:  10089528
Number of Compared accepted points:  10242930
Radii vector Reference: 0.2000
Radii vector Compared: 0.2000
*********Distance properties********
Maximal Vertical Distance: 0.6000
Maximal Horizontal Distance: 0.0800
Minimal  Horizontal lDistance: 0.0600
C:\Dades\PCM_log_DEGOTALLS_N_Inf_Jun21_Dec21_10_3_2022__16_5_0\PCM_3_DEGOTALLS_N_Inf_Jun21_Dec21_Differences.txt
Selected parameter: Closest point
Diferences point calculated:  9917298
Mean differences: 0.000656
Standart deviation differences: 0.038504
Mean Instrumental: -0.001000
Standart deviation Instrumental: 0.013000
Lower limit: -0.021575
Upper limit: 0.019149
*********Clustering properties********
Distance of neighbouring: 0.1000
Minimal number of points: 8
Number of clusters: 6848
Ending time: 3/11/2022  13:46:03
Ending cluster time: 3/11/2022  13:46:07
```

Ln 36, Col 25 100% Windows (CRLF) UTF-8

Fig. 6: Details of the PCM log.

7. Results

The whole process can be executed together after loading the two point clouds and reading the files (button "*Read Files"*) by filling in all the necessary configuration parameters. To do this, click the button "*All processes*". The other way to do it is step by step, load the point clouds and "Read Files", "*Vectorize*", either calculating the differences (button "*Differences*"), and clustering to create (button "*Clustering*") for this it is necessary to have the files loaded in each step.

The parameters that characterize each cluster can be viewed by clicking the "*View Results*" button.

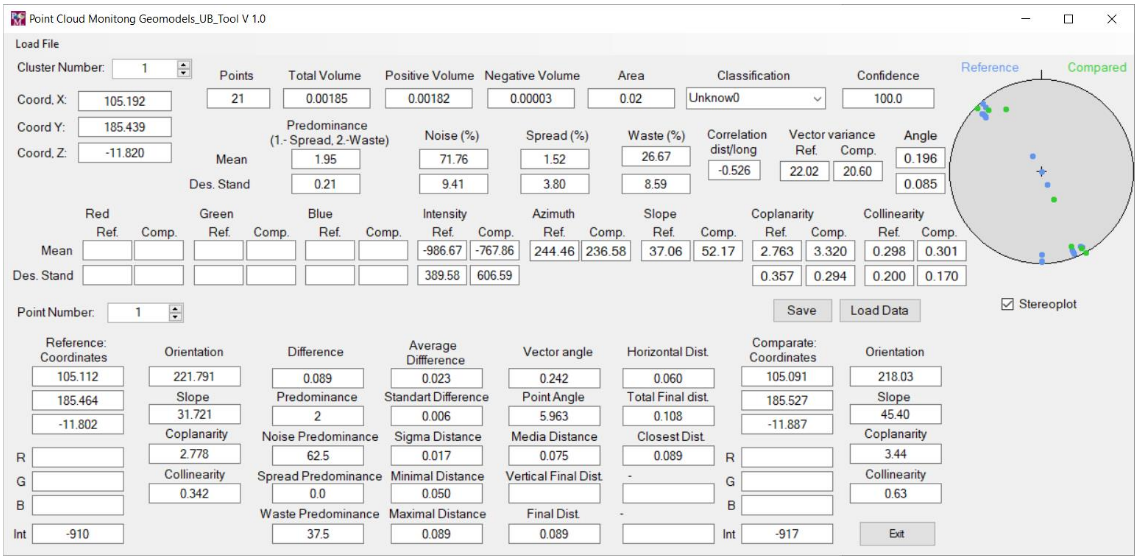


Fig. 7: Detail for the view results interface.