A new Approach to 3D Modeling of Blast Free Faces

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Abstract

This document investigates a newly developed technique with the objective of improving terrain triangulation models (horizontal/sub-horizontal and vertical/sub-vertical terrains), mainly blast free faces. The algorithm uses multi-linear regressions to generate the best point cloud projection plane by applying the residues modulus minimization so as to create the finest 3D triangulation model. A change of base is required to create a new set of coordinate axis and generate completely new projection planes. The projection plane residue analysis is inferred in order to avoid or reduce the outlier points. The data set is composed of 12 terrain models obtained from photogrammetry and a 3D Laser equipment that generates georeferenced cloud points. This new technic is validated by the analysis of the obtained critical burden by the improvement of the general aspect view of the terrains and the capacity of outlier's detection. The result and the quality of the algorithm demonstrates the improvement in the triangulation mesh, reducing errors in the calculation of over/under burden, free face volumes, cavities and, therefore, in the estimations of clearance/safety distances.

Introduction

In the great majority of Engineering projects, including the mines and quarries, are controlled by the terrain topography, especially in rock blasting operation where the critical burden on the blastholes and the real bench high are key parameter for the execution of an efficient blast (Bhandari, 1997, p. 168). This situation specifies the moved volumes, terrain changes and represents the real morphology of the project area (Gannett, 1906). In another way, topography encompasses the recording of terrain points and it three-dimensional quality representation (Berg, Cheong, Kreveld, & Overmars, 2008). Is in this last point that this document is focused on, since it depends on the quality of the treatment of terrain data, more specifically – the triangulation of terrain points.

In blast technical services, is very common the study of the free face and critical burden in order to evaluate it quality, avoiding security issues and production rates (Hagan, 1983).

Free face triangulation modeling optimization allows to:

- Create a reliable 3D model of the free face;
- Control possible cavities (or critical burdens) near boreholes that could generate fly rocks;
- Control overburdens and stemming projections;
- Control energy losses with projections and problems in dig rates;
- Control boreholes explosive charges by the identification of critical zones;
- Study free face movements and control influences in ore dilution (Domingo, Leite, Miranda, & Carrasco, 2015).

The free face control is one of the most important parameter in order to improve the blast results (Chadwick, 2016) being easy to comprehend that, with a better 3D modulation of it, the most accurate will be this control.

In the market, there are several softwares that tries to represent, with a certain degree of accuracy, the blast free faces geometry in order to give to the engineer an efficient tool to design the blast (Miranda, Couceiro, & Blasquez, Rioblast: Software de Diseño y Simulación de Voladuras en Entorno 3D, 2015).

In order to improve free faces 3D triangulation, the researchers developed a new technic application that automatically detects and eliminates outliers and uses the minimization of absolute residue[1] to make a better calculation of the triangulation. This document, presents the problem identification, an introduction to the background of this methodology and the description of the developed algorithm.

Background

Triangulation

To analyze a terrain is indispensable to generate a digital model of it, which will be based in the cloud point gathered by the most generic tools being a 3D Laser, photogrammetry or topographic stations (Ratcliff, 2008). A cloud points is characterized by a conjunct of points with regular (or non-regular) distribution and known altitude. In the other hand, a Digital Terrain Model (DTM) can be represented by a triangulated irregular network (TIN) with adjacent triangles connecting all the cloud points (Matos, 2008). This triangulated network is generated in a planar surface which is divided by irregular triangles,

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[1] Although this technic is rarely used, due to it mathematic complexity (Hamming, Introduction to Applied Numerical Analysis, 1971, p. 249), the solution can be achieved by Linear Programming Technics (Miranda, 2016).

in which the vertices are the known points and, when lifting each point to it real altitude level, each triangulation triangle is transformed in a triangle in a 3D space environment (Berg, Cheong, Kreveld, & Overmars, 2008, p. 192).

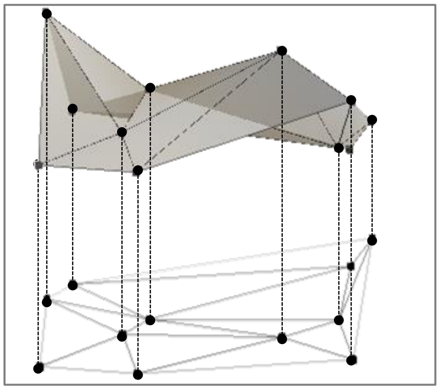

Figure 1. Generation of a terrain model from a planar triangulation of a set of points

There are several technics that creates the triangles networks (TIN), nevertheless, the most widely used is the known Delaunay Triangulation (MidtbØ, 1993), which was used to in presented research.

Voronoi Diagrams and Delaunay Triangulation

Voronoi diagrams are entirely correlated with Delaunay triangulation (Hjelle & Dæhlen, 2006). Being *a*, a point from a cloud point projected in a planar surface, a Voronoi diagram is defined by a geometric structure containing this point *a*, in which every point of its area is closer to *a* than any other projected point (Aurenhammer, Klein, & Lee, 2013). The Delaunay triangulation follows several principles/theorems in order to generate a triangular mesh between the points to be used to generate a digital model of a terrain. One of the Delaunay triangulation implication is that a circumcircle formed by three points of a Delaunay triangle does not include any other projected point (Aurenhammer, Klein, & Lee, 2013). A Voronoi's edge separates two points connected by a Delaunay edge.

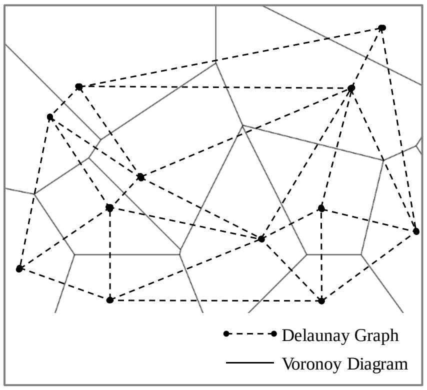

Figure 2. Voronoi diagram and Delaunay graph definition

Regression

Since the objective of this research was to improve the triangulation process, several tests were made in order to obtain the best projection plan that represents, in the best way possible, the cloud points. The modern interpretation of a regression, refers the dependence of a variable (dependent variable) respectively to one or more variables (explicative variables), with the objective to estimate the average value of a population (Novales Cinca, 1993).

Mathematically, a model, with *n* variable, is defined by:

$$\boldsymbol{Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + u} \qquad \textbf{Equation 1}$$

Where:
β = Linear coefficients
X= Explicative variables
Y= Dependent variable
u = Residue[2]

To determine the linear coefficients, that better adjust to our problem, is conceivable to use a technic of minimum least squares or minimum absolute residues. In the least squares methodology, a single outlier can generate a significant distortion due to the weightiness of the squaring of it distance to the regression model (Hamming, 1973). To minimize the sum of the absolute values, the researchers solved the following model (for a three-dimensional example), in order to find the decision variables $(u_i, \beta_0, \beta_1, \beta_2)$ that,

$$\text{Minimize} \quad \boldsymbol{\sum_{i=1}^{n} u_i} \qquad \textbf{Equation 2}$$

$$\text{Subject to} \quad \boldsymbol{Y_i - \hat{\beta}_0 - \hat{\beta}_1 X_1 - \hat{\beta}_2 X_2 \leq u_i,}$$
$$\boldsymbol{Y_i - \hat{\beta}_0 - \hat{\beta}_1 X_1 - \hat{\beta}_2 X_2 \geq -u_i}$$

$$\text{And} \quad u_i \geq 0, i = 1,2, \dots n$$

Outliers identification

In the process of gathering free face topographic points, several times are collected points that do not belong to the interest area. These points, mainly known as outliers, can be Laser 3D mistaken points, upper bench points included in the measurement, dust or passing vehicles in the measurement moment. In mathematical statistics these points are known as outliers (Czaplicki, 2014). In the current research was used the principle of 2,32σ, to define the outlier rejection region (98 %). Giving a regression plan π, if the distance between each point P_i and its projection in the plan π (P_i') is superior to the limits of outlier regions, this P_i is removed from the population.

Change of Basis

In order to triangulate the projected points on the best fit regression plan, is important to generate a new coordinates system that contains this plan. This operation is commonly named as change of base, in linear algebra (Lipschutz, 1994).

Profile definition – Dijkstra's Algorithm – Weighted Graphs

By the definition of a graph (Bondy & Murty, 1976), conjunct of mathematical object (nodes, vertices or points) connected between each other by edges, lines or arcs, is easy to infer that a triangulated set of points is itself a graph. In the calculation of critical profiles in free faces, is important to define the closest line between the terrain surface and a borehole. For that, the methodology followed in this research, is based on the Djikstra's algorithm that finds the shortest path between nodes (crest to toe), connecting Delaunay vertexes closest to the borehole. This kind of graphs, with different weighted edges, are denominated weighted graphs (Figure 11).

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[2] Stochastic perturbation or Stochastic error term (Gujarati & Porter, 2010, p. 40).

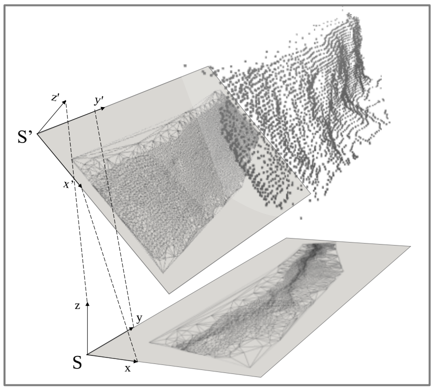

Figure 3. Generation of the new projected plan

Methodology

Outlier detection and elimination

The first step is detecting and eliminate the outlier’s points (Figure 12).

Triangulation in Horizontal Plan

The next step of this methodology was the representation of the terrain using a horizontal projection plan - Figure 4 a). On the Figure 4 b), is clear the agglomeration of projected points which will generate a conjunct of errors on the identification of points to be connected (during the triangulation algorithm), to generate the 3D model, to better describe the real terrain.

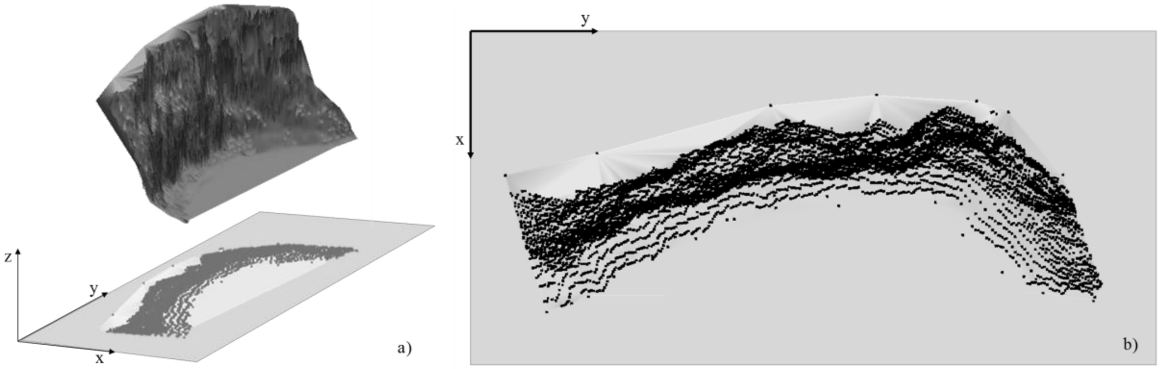

Figure 4. a) Cloud point and projection plan; b) Cloud point projected on the plan

The visual results from this technic can be observed on the Figure 5.

Since this procedure presents several irregularities, the logic behind it was to generate a new projection plan that better adjusts the free face points.

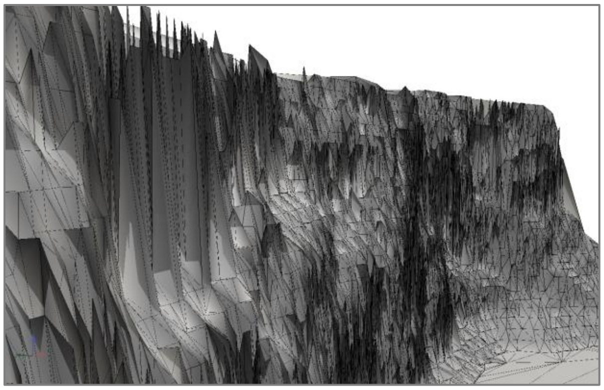

Figure 5. Effects of free face triangulation using a horizontal projection plan

Triangulation in a Minimum Square (M.S.) Adjusted Plane

To improve the triangulation, and based on the free face cloud points, the researchers recurred to the generation of a regression plan by the minimum square adjustment - Figure 6 a). As observe on Figure 6 b), there are a great improvement on the visualization of the projected data.

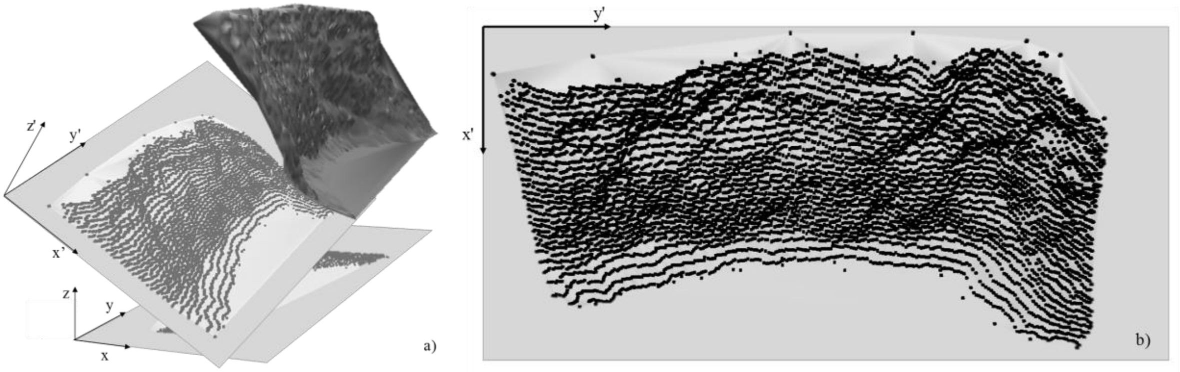

Figure 6. a) Cloud points and M.S. projection plan; b) Cloud points projected on the plan

The terrain definition suffered an improvement nevertheless, when the analyzed terrain presents reminiscent outliers, this methodology offers some irregularities (Figure 7).

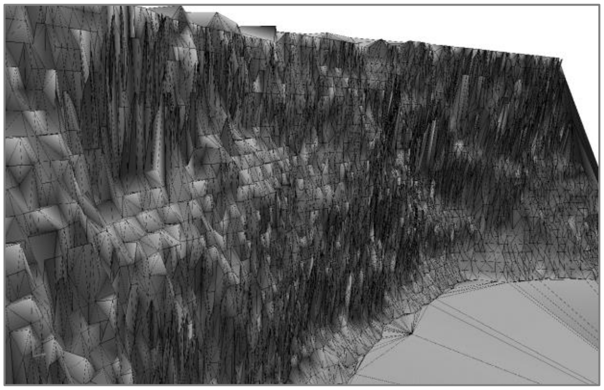

Figure 7. Effects of free face triangulation using a horizontal minimum square regression plan

To eliminate this kind of outliers on free faces models, the researches decided to generate the terrain triangulation by recurring to a minimum residue regression plan.

Triangulation in a Minimum Residue (M.R.) Adjusted Plan

The reminiscent outliers, on this methodology has a much lower influence than in the previous methods presented. In the Figure 8, is possible to observe the differences on the projection plane and in the results of the terrain triangulation (Figure 9).

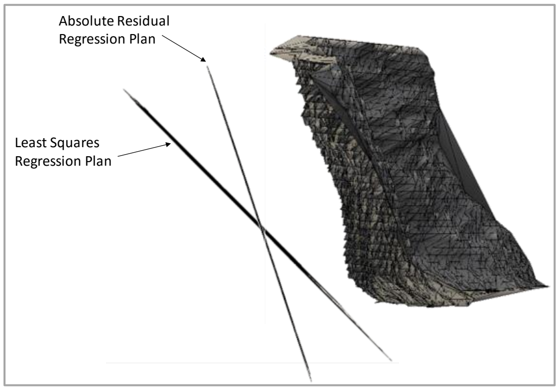

Figure 8. Comparison of projected plans M.S - a). vs. M.R. b)

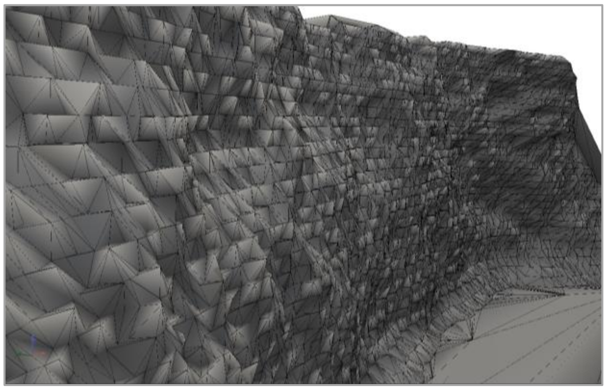

Figure 9. Results of the application of M.R. regression

This regression plan, compared with the previous methodologies is the one that better explains the cloud points. However, if the cloud represents several areas like corners or different direction walls, this algorithm can also fail in the identification of the preferential points to triangulate.

Triangulation in a Multiple Minimum Residue Adjusted Plans

The solution founded by the researchers was the generation of multiple plans (adjusted by minimum residue regression) in order to represent, in the best way possible, all the conjunct of the cloud points - Figure 10 .

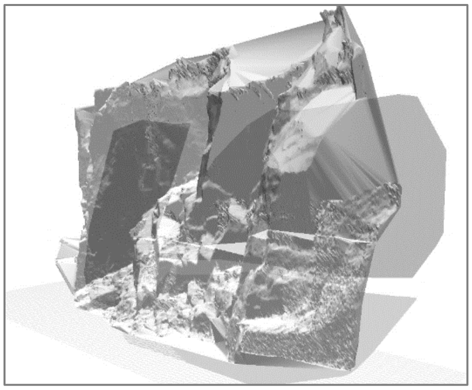

Figure 10. Multiple M.R. plans

Visually, this technic has a great power of definition when comparing with the real terrain. The peaks generated in the previous examples are avoided when applied this technic which is an indicative of the quality of the triangulation.

Critical Burden Identification

In this research was used a graph algorithm to determine the shortest path between the crest and toe nearest to the borehole. This technic, using the Djikarta algorithm (with the correct selection of the weights) determines the small distance between the hole and the free face.

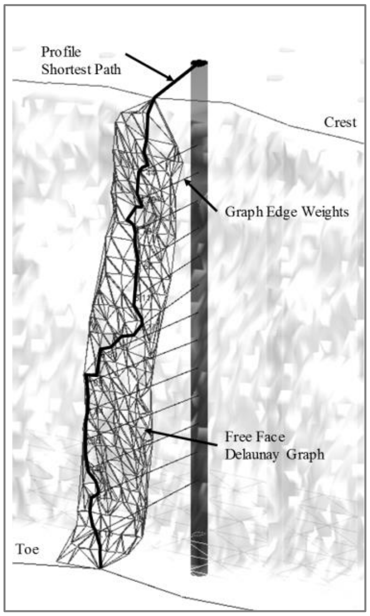

Figure 11. Dijkstra's algorithm applied to free face profiling

Results and Discussion

Database

The database, on which the algorithm was tested, is composed by 12 free face cloud points from an open pit quarry - Madalena Quarry (SOLUSEL, Lda), Vila Nova de Gaia (Portugal) - and, in this case, the total analyzed terrain points number is 4.800.000. Was used a blast design software - O-Pitblast® - Blast Design&Optimization Platform - to analyze the data retrieved from the field tests. Was analyzed each terrain quality representation (using the four triangulations technics, previously described) and determined the critical burden for each hole in its respective model (48 holes).

Outliers

The outlier's detection algorithm proved to be very precise finding points that does not belong to the free face. Visually the effect is showed in Figure 12.

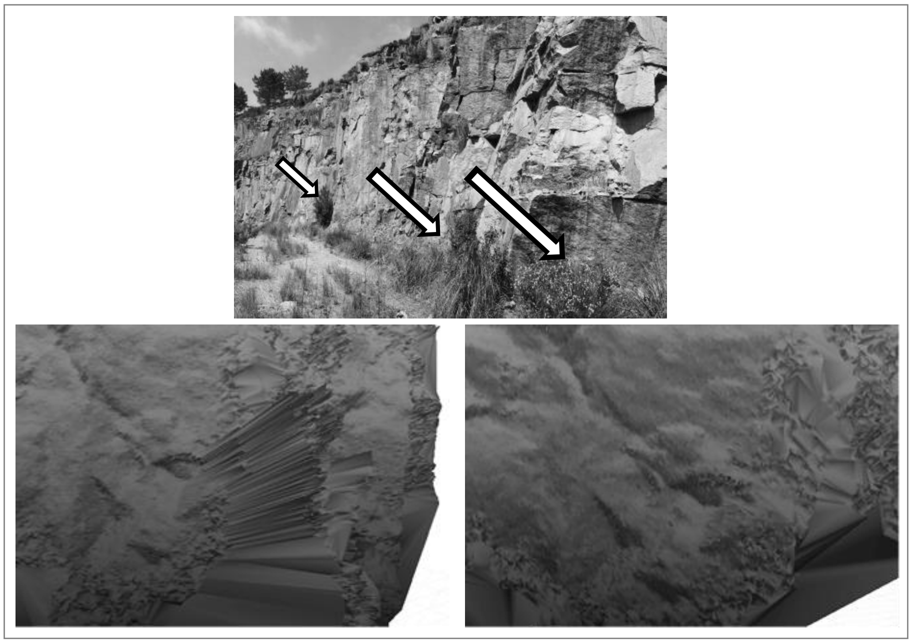

Figure 12. Outliers detection and elimination

Critical Burdens Identification

The technic identifies more dangerous critical burden on the borehole profile. On Figure 13 the reader can compare the critical burden calculated by the horizontal, least squares regression and minimum absolute residue triangulation plan.

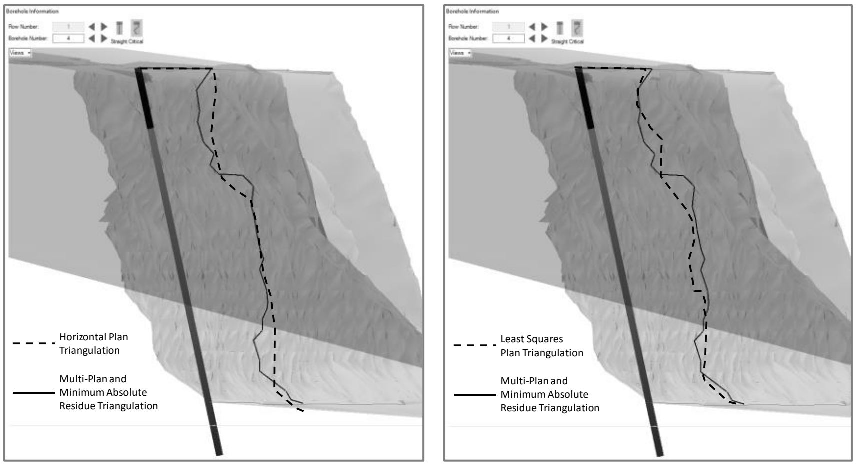

Figure 13. Critical Burden Identification

Conclusion

The identification of critical burden is a very important situation in the moment of planning a blast. An inadequate calculation of this situation can lead either to fly-rock generation (compromising human and/or equipment losses), to air blast issues (with generation of noise and air blast waves) and also to vibrations and fragmentation issues (secondary blast).

This technic expanded the horizon of the free face data treatment. Was identified improvements on the process of identification of critical burdens and was proved the accuracy of these measures. An inadequate process of outlier's identification can derail a correct conclusion about a project due to its tendency to falsify the developed terrain models.

The quality of terrain representation suffered an improvement when the triangulation plan was calculated by the minimization of absolute residues.

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