1st International Conference on

Algebraic and Symbolic Computation

PROCEEDINGS

09-10 September, IST

Lisbon, Portugal

ISBN 978-989-96264-5-4

ISBN 978-989-96264-5-4

SYMCOMP 2013 - 1st International Conference on Algebraic and Symbolic Computation

Proceedings in digital support (pen drive)

Edited by APMTAC – Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional

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September, 2013

Introduction

The Organizing Committee of SYMCOMP2013 – 1st International Conference on Symbolic and Algebraic Computation welcomes all the participants and acknowledge the contribution of the authors to the success of this event.

This First International Conference on Symbolic and Algebraic Computation, is promoted by APMTAC - Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional and it was organized in the context of IDMEC/IST - Instituto de Engenharia Mecânica. With this ECCOMAS Thematic Conference it is intended to bring together academic and scientific communities that are involved with Algebraic and Symbolic Computation in the most various scientific areas

SYMCOMP 2013 elects as main goals:

To establish the state of the art and point out innovative applications and guidelines on the use of Algebraic and Symbolic Computation in the numerous fields of Knowledge, such as Engineering, Physics, Mathematics, Economy and Management,...

To promote the exchange of experiences and ideas and the dissemination of works developed within the wide scope of Algebraic and Symbolic Computation.

To encourage the participation of young researchers in scientific conferences.

To facilitate the meeting of APMTAC members (Portuguese Society for Theoretical, Applied and Computational Mechanics) and other scientific organizations members dedicated to computation, and to encourage new memberships.

We invite all participants to keep a proactive attitude and dialoguing, exchanging and promoting ideas, discussing research topics presented and looking for new ways and possible partnerships to work to develop in the future.

The Executive Committee of SYMCOMP2013 wishes to express his gratitude for the cooperation of all colleagues involved in various committees, from the Scientific Committee, Organizing Committee and the Secretariat. We hope everyone has enjoyed helping to birth this project, which we are sure will continue in the future. Our thanks to you all.

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Contents

SYMCOMP 2013
Lisbon, 9-10 September 2013

CHARACTERIZATION AND MODELING OF BUILDING CRACKS USING 3D LASER SCANNING AS REHABILITATION SUPPORT

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Keywords: 3D laser scanning, surface reconstruction, point clouds, symbolic computation

Abstract. *Surface reconstruction is an important issue in geometric modelling. It has received a lot of attention in the computer graphics community in recent years because of image technologies development, namely laser scanning technology, and their wide applications in areas such as reverse engineering, product design, medical devices design and archaeology, among others. In building and rehabilitation areas, laser scanning has been widely applied in the field of architecture for the survey of geometric characteristics of historic buildings. The high speed and accuracy of data acquisition allows the reconstitution of 3D models with a level of detail and precision, exceeding conventional techniques. With this work, it is intended to visualize data acquired from 3D laser scanning and develop a crack characterization and modelling algorithm. This study is developed and implemented using Mathematica algebraic and symbolic platform tools, and in a final stage the open-source application Meshlab is used for the global assembly visualization. Concerning the methodology used, the first approach is the development of automatic extraction of several non-disjoint points process, corresponding to a surface portion. After this, two types of filters are used: the first to eliminate redundant points and thus providing a more efficient cloud, the other to detect crack points.*

Mathematica allowed us to visualize the interpolations surface of the points sample and obtain an approximation of the surface reconstruction.

1 Introduction

The 3D laser scanning technology has brought a great evolution of the traditional survey methods, allowing increased precision, detail and reduced errors and costs. [1]

Different approaches have been taken to the 3D laser scanning technique, including the work of Hoppe, De Rose et al which popularized laser range scanning as a graphics tool [2], and the radial basis function method of Carr et al. [3].

Laser scanning is based upon time-of-flight or ranging finding technique principles. Laser scanners devices have a laser diode that sends a pulsed laser beam to the object which image one wants to acquire. The pulse, when reflected by the object, sends part of the light back to the receiver. The time that the light needs to travel from the scanner device to the object and back is then measured. Knowing this time and considering the speed of light value and the orientation of the pulsed laser, the distance from the scanner to the object can be found. Depending on the device hardware and on the distance to the object, it is possible to achieve high resolutions of a full 360^o scan in less than 5 minutes.

When surveying large objects, the scanner can be used in different positions, resulting in a number of point clouds. This enables to complement data of hidden areas on a laser scan position that can be seen in another position. These clouds can be subsequently merged by using specialized image processing software as MeshLab. Digital survey data result into dense point clouds, where each point is represented by coordinates in 3D space, (x, y, z) from the scanner position, passive colors (RGB), normal vectors and reflected intensity of the laser beam. The acquisition of this data, enables an approximation to the shape reconstitution of the 3D objects and subsequent refinement of its geometrical modelling. Although this high density of points can be viewed as an advantage because relevant information lies in it, it is also a disadvantage not only because there is always unwanted noise points but also because associated to dense clouds we have higher computational requirements and costs.

To obtain and analyse the shape of the scanned surfaces, it is primarily necessary to convert irregularly distributed point data into 3D surface useful information. To achieve this, surface reconstruction algorithms are used, being roughly classified into polygonal and parametric approaches. An example of polygonal techniques is 3D Delaunay triangulation which creates irregular, triangular patches based on simple linear interpolation between the points in 3D space. Examples of parametric techniques are NURBS (Non-Uniform Rational B-Splines) or Fast RBF (Radial Basis Functions), which use parametric functions to define surface patches. Parametric techniques create more "realistic" surfaces and more accurate representations, particularly in areas where data is missing, but it requires more computing power and time than polygonal interpolation techniques.

From the literature review carried out, it can be concluded that the use of this technique is increasing as its advantages become more disseminated in different areas of knowledge and particularly in the areas of health monitoring and maintenance/rehabilitation. As a brief state of the art, in this context one can refer the published work due to Al-

Neshawy et la (2009) [4] which presented a study focused on the objective to find the potential of the terrestrial laser scanning technique to detect the deterioration on the surfaces of the building facades and to quantitatively measure the dimensions of the damaged areas. Their work was focused on detecting the bowing of marble cladding and the surface delamination of brick facades. Field measurements were carried out using a terrestrial laser scanner. Measurements of the bowing of the marble panels were also carried out manually with a so-called "bow-meter". The authors concluded that laser scanning technique gives a reasonable method for measuring the bowing of marble panels and the delamination of brick building facades. Berenyi et al. (2010)[5] developed a work focused on the confirmation of the accuracy of the results of engineering survey carried out upon point clouds. Complex laboratory measurements were performed to analyse the main accuracy values as well as the effect of the presence of different materials, colors and the incident angle. A methodology to combine the technology of the terrestrial laser scanner with the techniques of digital image processing in order to study damages on stony materials that constitute historical buildings was presented by Armesto-Gonzalez et al. (2010)[6]. To this purpose they used intensity data from three terrestrial laser scanners with different technical specifications. According to the authors, the results show the potential of the use of intensity data from terrestrial laser scanner for the recognition and characterization of certain pathologies in building materials. Sun et al. (2012)[7] studied the pavement crack detection using 3D laser scanning. They analysed the pavement profile signal characteristics and the changeability of pavement crack characteristics, and proposed a method based on the sparse representation to decompose pavement profile signal into a summation of the mainly pavement profile and cracks. According to these authors, in addition to the non-destructive character of this technique, it can be used very effectively due to its ability of discriminating dark areas, which are not caused by pavement distress such as tire marks, oil spills and shadows. More recently Shen-En (2012)[8] proposed laser scanning technique as an ideal bridge field inspection tool, not only because of the non-contact nature and the ability of sensing from a distance, but also due to the limited disruption to traffic, low labour requirements and the possibility to provide permanent electronic documentations of the temporal changes of a structure. This author considers that laser scanning enables achieving precious information that should however be complemented with bridge inspection, or other additional evaluation surveying methodologies. A methodology for extracting information about the presence of biological crusts on concrete structures using terrestrial laser scanners was proposed by Gonzalez-Jorge et al. (2012)[9]. The goal of this methodology is to integrate all the available information, range, intensity and color, into the extraction work flow, considering primarily two algorithms. The first algorithm was used to build an orthoimage using the intensity data obtained from two different scanners, and the second tested two different classifiers, K-means and Fuzzy C-means, to automatically extract information about the areas of concrete where biological crusts present. In the present study the symbolic and algebraic computation application, Mathematica was used to in a preliminary stage to process the points cloud regarding point selection, partitioning and 3D visualization. Due to the large amount of information associated to a point cloud, it was found necessary to developed algorithms aiming to eliminate points with redundant or needless information for this study. After a successful decimation of the point cloud, other algorithms were developed to retrieve information regarding cracks and wall characteristics, aiming lower computational requirements as possible.

2 Point Cloud Analysis and Modeling

Using data acquisition devices commonly known as laser scanners, it is therefore possible to obtain information about the desired object through a great number of points that form the cloud. Depending on the data acquisition method, this cloud of points can be organized if topological information for each point is known, or unorganized otherwise. In this case our clouds where constituted by points having 10 coordinates $(x, y, z, nx, ny, nz, a, r, g, b)$, where (x, y, z) are associated to each point's spacial Cartesian coordinates, (nx, ny, nz) are the normals at the point(this normals are computed using several other points in its close neighborhood, (r, g, b) is the RGB color code and a is an integer label

This paper introduces a method for the parametrization of a cloud of unorganized points, based on a parallelepipedic subsets segmentation, bounded by a closed path of curves.

Other methods start from an underlying 3D triangulation of the points cloud. Generally, through iterative steps, a topologically identical 2D triangulation is obtained, defining the parameter values of the vertices in the domain plane. These methods differ in the way how the transformation is performed from 3D to 2D. Here we base our choice on the global shape of the points cloud.

The normals (nx, ny, nz) computed by the laser scanner are based on local shapes. However it was found useful to calculate a more accurate information concerning the resulting point clouds.

2.1 Outline of the proposed algorithm

Given a points cloud we begin by:

1. Construct a disjoint decomposition using as criteria the space localization.

2. Next, every part is filtered eliminating unnecessary points. Here we use a combined filter with the the spacial and color information.

3. At the next step we determine the global shape of the points cloud, and we correct the normals vectors at each point using this information. Here we find also the parallelogram containing more points from the cloud and we use this information on the next step.

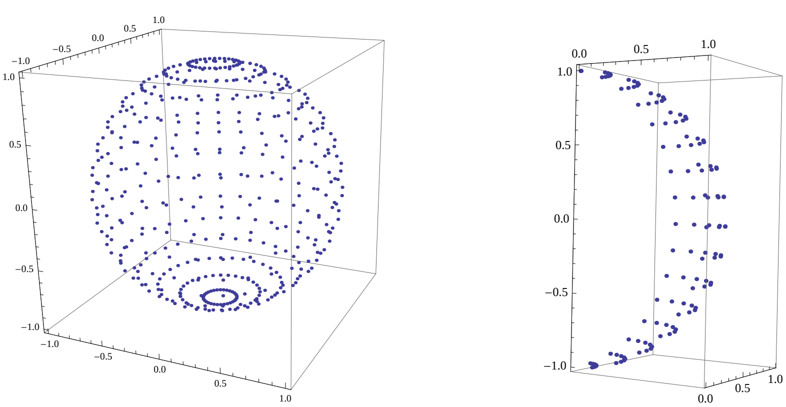
4. Finally, using a criteria like as at *implicit function theorem* adapted to the study of normal vectors, we determine a parametrization of the plan surface.

To enable testing every step we started using as example a spherical surface and rabbit cloud points available at Mathematica examples. We have also used Mathematica for 3D visualization of reduced points cloud and Meshlab for the assembly of the parts above mentioned or for global visualization.

2.2 Preliminary Studies

In order to replace the current cloud-approximation problem by an equivalent set of N approximation-problems, the present point cloud must be partitioned into N subclouds. To this purpose, the following procedure is employed to identify the subcloud: For each coordinate, we find its maximum and its minimum, using Mathematica functions. With this information we know the smallest parallelepiped that contains the points-cloud. Now it is possible to split the parallelepiped as wanted.

For the first test, we use a points cloud from a spherical surface. With the above procedure it was possible to decompose the points-cloud as wished for a number of N parts. It is relevant to note that this decomposition is non overlapping, but if its necessary for assembly reasons we can define an overlapping decomposition.

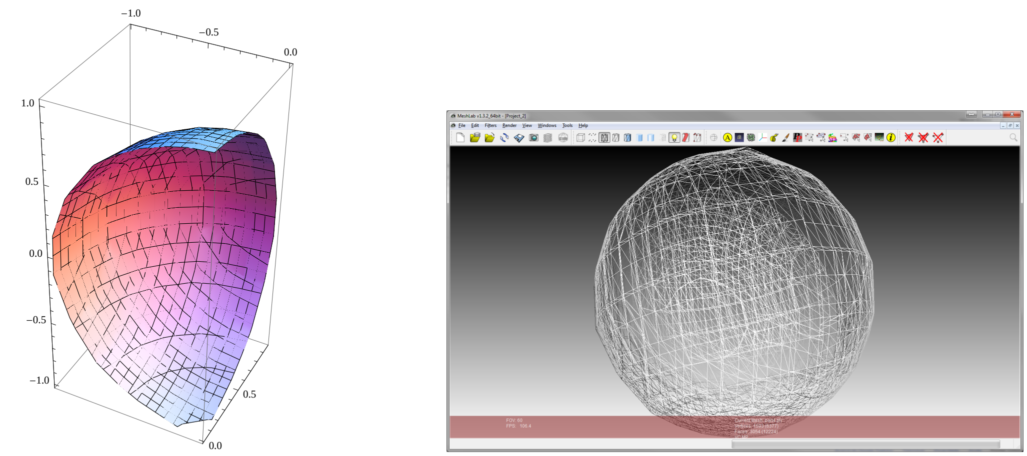


(a) Global representation

(b) Decomposition parts representation

Figure 1: Sphere Point Cloud representation

By using Mathematica surface reconstruction tool, it was possible then to rebuild the surface of the analysed object. This reconstruction can be achieved by interpolating the points sample with "ListSurfacePlot3D" function. The results can be exported in PLY file format which in addition to the point coordinates, also includes the normal vectors of each triangular surface used for the representation of the sphere surface (figure 2a).



(a) Surface reconstruction with Mathematica functions

(b) Merged parts in MeshLab

Figure 2: Surface reconstruction

The reason for using this format is related to portability, as the data can be read and interpreted with other programs, such as MeshLab (figure 2b).

ListSurfacePlot3D is a Mathematica reconstruction function that tries to find a surface as close as possible to the data. Regions with a low number of sampled values will introduce holes on the surface. Data points in ListSurfacePlot3D are used to construct a distance function that is used to find the zero-level surface. The original points are not part of the final result. Thus this function utilization has some limitations, as we can obtain incorrect results if we do not use a sufficiently large number of points.

3 Characterization of cracks

Using the laser scanner device, several 3D scans were performed inside a building from ISEL campus. After visualizing the resulting point clouds with Meshlab, a small portion of a cracked wall containing about $100K$ points was selected and exported for further algorithm development purposes (figure 3) and processing. This procedure is justified not only because the interest object was the wall crack, but also due to CPU and RAM economy reasons.

To determine crack characteristics, the focus should be firstly directed to the wanted data. Cracks on walls may have different shapes and be classified according to different types. However we can point out characteristics that are common in most cases:

- Once a crack is a small opening in a wall, the visualization of a fissure is generally dark.
- According to the case and severity of cracking, all achieve some depth and length in the wall

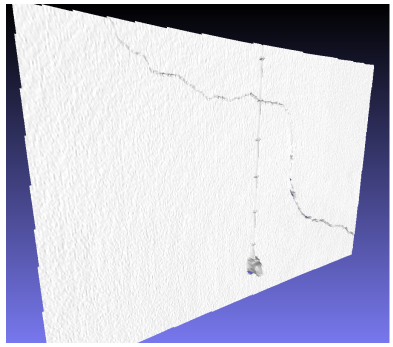


Figure 3: Points cloud representation in Meshlab

- Cracks can present widths that usually vary from $0,1mm$ up to $> 10mm$. These can develop on the plane of the wall or on a perpendicular direction of the wall.

At this point it is important to reduce the point density in areas that have no useful information while maintaining all points in areas require a more detailed description. Aiming this objective, some algorithms were considered.

Internal walls in a building usually present one color, so under these conditions and considering the point cloud also has RGB information, the following algorithm was developed to select only points within a given RGB range (0-255).

```
SELECRGB = Function[{L, r1, r2, g1, g2, b1, b2},
 Module[{nL, kL, w, j},
    nL = Length[L];

    w = Select[
      L, (r1 <= #[[7]] && #[[7]] <= r2) &&
         (g1 <= #[[8]] && #[[8]] <= g2) &&
         (b1 <= #[[9]] && #[[9]] <= b2) ];
    w
    ]];
```

Function SELECRGB

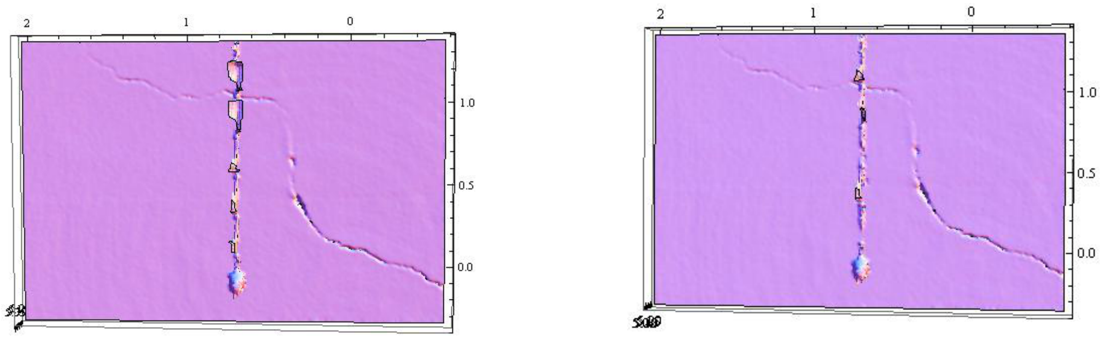
Carrying out tests of this procedure on the cloud, we find that points with lighter color characteristics can go up to 50 percent of the cloud point sample which represents a large number of points with no relevant information at this point. Therefore we selected the darker RGB colors, from 0 to 245 and the resulting point cloud presented only the crack and the power cable.

With the function " SELECRGB " we were able to select only areas that show different color characteristics. To avoid the risk of removing too much information near darker areas (cracks), we added an exception. This consist in excluding all areas inside a circle that contain more then determined ratios of darker points. If the ratio is high on dark points, no points are removed from this area. On the other side, if the ratio on lighter points is higher, all dark points are removed.

```
RGBFILTER=
  Function[{L, rr, tx, r1, r2, g1, g2, b1, b2},
   Module[{nL, kL, V, W, j, i, k, n, a, b, c},
    nL = Length[L]; V = Array[0 &, {nL}]; W = {};

    Do[
     If[(r1 <= L[[j, 7]]  &&
         L[[j, 7]] <= r2) &&
         (g1 <= L[[j, 8]] &&
          L[[j, 8]] <= g2) &&
         (b1 <= L[[j, 9]] &&
         L[[j, 9]] <= b2) ,
                           V[[j]] = 1]
     , {j, 1, nL}];
    ;
    Do[
     If[V[[j]] == 0,
      k = 0;
      n = 0;
      Do[
       a = Abs[L[[i, 1]] - L[[j, 1]] ];
       b = Abs[L[[i, 2]] - L[[j, 2]] ];
       c = Abs[L[[i, 3]] - L[[j, 3]] ];

       If[( Max[a, b, c] < rr ), k++];
       If[( Max[a, b, c] < rr && V[[i]] == 1), n++]

       , {i, 1, nL}]; If[n > tx*k, V[[j]] = 1],
      ]
     , {j, 1, nL}];
    W
    ]];
```

Function RGBFILTER

The following figures represent a comparison of the original data surface reconstruction (figure 4a) and the reduced version with 20 percent less points (figure 4b). The result is an almost similar representation without affecting the areas we are studying.



(a) Original data Representation

(b) Reduced data Representation

Figure 4: Reconstructed surface comparison

With these functions we can reduce and isolate the convenient points to find the wall plan equation. With this reference it is then possible to determine the global shape of the points cloud, correcting the normals vectors at each point.

For the wall plan equation we also find the parallelogram containing more points from the cloud as shown at figure 5.

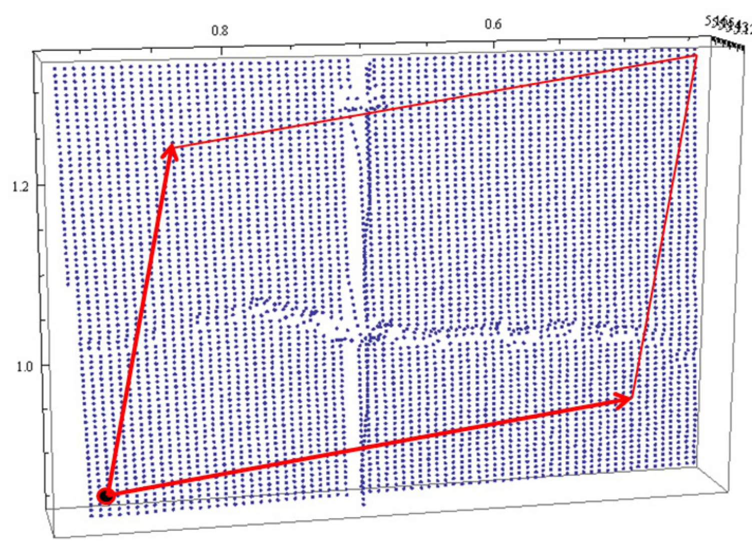


Figure 5: Point cloud vectorial analysis

The normalized vector was determined using the following algorithm:

```
NORMALV = Function[{L, imp},
   Module[{nL, i, j, k, r, rx, VN, VNN, V, W, VP, NVP, A, B, pin },
    nL = Length[L]; V = Array[0 &, {nL, 2}]; VN = Array[0 &, {nL, 3}];
     VP = Array[0 &, {3}];  NVP = Array[0 &, {3}];
    W = Array[0 &, {6}];
    A = Array[0 &, {3}]; B = Array[0 &, {3}];

     r = 0.;
      Do[rx = Norm[L[[i, All]] - L[[j, All]]];
        If[ (rx > r) , V[[j, 1]] = i; r = rx ; A = L[[i, All]] - L[[j, All]]];
        , {i, nL}];

     r = 0.;
      Do[B = (L[[i, All]] - L[[j, All]]); rx = Norm[B]; pin = A.B;
        If[ (rx > r) && (V[[j, 1]] != i) && ( pin < .2), V[[j, 2]] = i; r = rx ];

               , {i, nL}];

     , {j, nL}];


     r = 0;
    Do[
     A[[All]] = L[[V[[j, 1]], All]] - L[[j, All]];
     B[[All]] = L[[V[[j, 2]], All]] - L[[j, All]];
     VN[[j, All]] = Cross[A, B];
     (* Print["norma ",Norm[VN[[j,All]] ] ]; *)
     rx = Norm[ VN[[j, All]] ];
      If[ rx > r, r = rx; k = j ];

     , {j, nL}];

    NVP = Normalize[ VN[[k, All]] ];

    W[[1 ;; 3]] = NVP ; W[[4 ;; 6]] = L[[k, 1 ;; 3]];

    W
    ]];
```

For the plane representation:

```
PPP = Function[{L, V}, Module[{X, Y, Z, x1, x2, y1, y2, z1, z2, W},
    W = Abs[V[[1 ;; 3]]];
    X = L[[All, 1]]; x2 = Max[X]; x1 = Min[X];
    Y = L[[All, 2]]; y2 = Max[Y]; y1 = Min[Y];
    Z = L[[All, 3]]; z2 = Max[Z]; z1 = Min[Z];

    Which[W[[1]] == Max[W],

     ParametricPlot3D[{
       V[[4]] - (V[[2]]/V[[1]])*(y - V[[5]]) - (V[[3]]/V[[1]])*(z -
           V[[6]])
                                                              , y,
       z}, {y, y1, y2}, {z, z1, z2},
      BoxRatios -> {x2 - x1, y2 - y1, z2 - z1},
      AxesLabel -> {"x", "y", "z"}],
                 W[[2]] == Max[W],

     ParametricPlot3D[{x,
       V[[5]] - (V[[1]]/V[[2]])*(x - V[[4]]) - (V[[3]]/V[[2]])*(z -
           V[[6]])
                                                              ,
       z}, {x, x1, x2}, {z, z1, z2},
      BoxRatios -> {x2 - x1, y2 - y1, z2 - z1},
      AxesLabel -> {"x", "y", "z"}],
                 W[[3]] == Max[W],

     ParametricPlot3D[{ x, y,
       V[[6]] - (V[[1]]/V[[3]])*(x - V[[4]]) - (V[[2]]/V[[3]])*(y -
           V[[5]])
                                                              }, {x,
       x1, x2}, {y, y1, y2},
      BoxRatios -> {x2 - x1, y2 - y1, z2 - z1},
      AxesLabel -> {"x", "y", "z"}] ]

    ]];
```

At this point we are able to isolate cracks points and estimate the size of the crack.

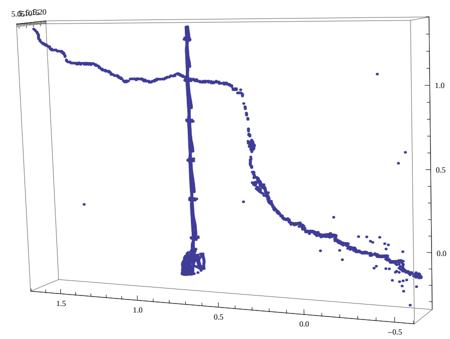


Figure 6: Crack and power cable points

From the knowledge of the plane equation, it was also possible to remove all points pertaining to the cable, leaving only the crack which we intend to analyse. The distance from the plane to the end of the crack was determined according to the following equation:

$$\frac{a * NP[i,1] + b * NP[i,2] + c * NP[i,3] + d}{\sqrt{a^2 + b^2 + c^2}} < dist$$

which in Mathematica is written as:

```
planoREMOVpts =
 Function[{NP, dist}, Module[{a, b, c, x0, y0, z0, nL, d, W, valor},
   nL = Length[NP]; W = {};

   a = normalplano[[1]];
   b = normalplano[[2]];
   c = normalplano[[3]];

   x0 = normalplano[[4]];
   y0 = normalplano[[5]];
   z0 = normalplano[[6]];

   d = -(a*x0 + b*y0 + c*z0);

              valor = dist * Sqrt[a^2 + b^2 + c^2]*(-1);
   Do[
    If[ (a*NP[[i, 1]] + b*NP[[i, 2]] + c*NP[[i, 3]] + d ) > valor,
     AppendTo[W, NP[[i, All]]]  ], {i, nL}];
   W
```

4 Conclusions

3D laser scanning generate point clouds that retain a huge volume of information, which in some extent can be redundant. Thus only part of it, is effectively important for the objective of this study. In a first phase of this study, one have selected only points pertaining to wall areas with cracks. By carrying out this first selection the point cloud was reduced from 10 million points to $100K$ points. In the interest areas we were also able to reduce density without affecting the cracks under analysis by applying several algorithms, which yielded a resulting point cloud fairly faster to process and with minor computational requirements. At this point a faster achievement of results was also obtained. With the resulting cloud point, other algorithms were developed and applied to retrieve crack information, such as width, depth and length. As shown through the examples shown in this work it can be concluded that the computational procedures developed can be applied with an effective gain in terms of computational effort. These procedures present a great potential to be applied on these type of problems for a complete structure, as they can give us a detailed scenario with the positioning and severity of one or multiple cracks, providing valuable information for diagnosis and rehabilitation.

5 Acknowledgements

The authors wish to acknowledge the partial financial support given by FCT through Project PTDC/ATP-AQI/5355/2012.

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