

OUTCROP EXPLORER: A POINT-BASED SYSTEM FOR VISUALIZATION AND INTERPRETATION OF LIDAR DIGITAL MODELS

Outcrop Explorer: um Sistema Baseado em Pontos para Visualização e Interpretação de Modelos Digitais LiDAR

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ABSTRACT

The use of LiDAR-based models for natural outcrops and surfaces studies has increased in the last few years. This technique has been found to be potential to represent digitally tridimensional data, thus it increases the quality and amount of data available for interpretation by geoscientists. Researchers, in computations, face difficulties in handling the huge amount of the data acquired by LiDAR systems. It is difficult to visualize efficiently the point cloud and convert it to high-quality digital models (DMs) with specific interpretation tools. Some in-house and commercial software solutions have been developed by some research groups and industries, respectively. However, all solutions must consider the large database as the pain point of the project. Outcrop Explorer has been developed to manage large point clouds, to provide interpretation tools, and to allow integration with other applications through data exporting. In terms of software architecture, view-dependent level of detail (LOD) and a hierarchical space-partitioning structure in the form of octree are integrated in order to optimize the data access and to promote a proper visualization and navigation in the DM. This paper presents a system developed for visualization, handling and interpretation of digital models obtained from point clouds of LiDAR surveys. This system was developed considering the free graphic resources, the necessities of the geoscientists and the limitations of the commercial tools for interpretation purposes. It provides an editing tool to remove noise or unnecessary portions of the point cloud and interpretation tools to identify lines and planes, as well as their orientations, and it has different exporting formats. However, being an open source project much more collaborative development is necessary.

Keywords: Terrestrial Laser Scanner, Point Clouds, Level of Detail, Octree, OpenGL.

RESUMO

O uso de modelos baseados na técnica LiDAR para estudos de superfícies e afloramentos tem aumentado sobremaneira nos últimos anos. Esta técnica tem potencial para representar digitalmente dados tridimensionais de forma a aumentar a quantidade e a qualidade dos dados disponíveis para interpretação pelos geocientistas. Pesquisadores na área de computação tem sido desafiados a manusear de forma eficiente as grandes bases de dados adquiridas pelos sistemas LiDAR. É particularmente difícil visualizar nuvens de pontos de forma eficiente e convertê-las em modelos digitais de

alta qualidade com ferramentas de interpretação. Alguns aplicativos comerciais e acadêmicos tem sido desenvolvidos nos últimos anos pela indústria e por grupos de pesquisa, respectivamente. Entretanto, todos os aplicativos devem considerar a grande quantidade de dados como o ponto crítico do projeto. Outcrop Explorer tem sido desenvolvido para manusear nuvens de pontos de grande porte, fornecer ferramentas básicas de interpretação e permitir integração com outros aplicativos por meio da exportação de dados. Em termos de arquitetura de software, nível de detalhamento (LOD) e estrutura hierárquica de divisão do espaço na forma de octree foram integrados para otimizar o acesso aos dados e permitir visualização e navegação de alto desempenho no modelo digital. Este artigo apresenta um sistema desenvolvido para visualização, manuseio e interpretação de modelos digitais derivados de nuvens de pontos adquiridas pela técnica LiDAR. Este sistema foi desenvolvido considerando recursos gráficos gratuitos, as necessidades dos geocientistas e as limitações das ferramentas comerciais disponíveis para interpretações. Fornece ferramentas de edição para a remoção de ruídos e partes indesejáveis da nuvem de pontos, ferramentas de interpretação para identificar e orientar linhas e planos diretamente no modelo digital, além de diferentes formatos de exportação. Entretanto, como um projeto de código aberto, o desenvolvimento do aplicativo depende da ação colaborativa de usuários e interessados.

Palavras chave: Laser Escâner Terrestre, Nuvem de Pontos, Nível de Detalhe, Octree, OpenGL.

1. INTRODUCTION

The technological evolution has brought a number of advanced solutions for applications in many different knowledge areas in the last two decades. In general, the geotechnological approach has permitted geoscientists to acquire huge amount of spacialized digital data. The more data are collected by sensors, the larger is the database size, and more processing is required to provide high-quality images or digital models for interpretation. The size of the database is directly related with the spatial resolution, i.e., the number of points per unit area. This characteristic is crucial for representing outcrops and surfaces due to the multiscale nature and any detail can be fundamental for interpretation purposes.

The Light Detection and Ranging (LiDAR) technology, especially terrestrial laser scanners (TLS), has permitted geoscientist to improve the quality of the analyses and interpretations through digital model (DM), which is a digital representation of data collected from surfaces that can be inspected, handled, and interpreted. Under a geological point of view, outcrops provide an intermediary approach between the kilometric and millimetric work scales and field data acquisition is often underexplored. As an example, the seismic data have their resolution limited to few decameters whereas lithological logs and thin sections are laterally restricted to few centimeters. Therefore, DMs have become an interesting way to integrate surface and subsurface data. This intermediary work scale

allows acquiring much more data using remote sensors, e.g., laser scanners with similar or superior quality obtained from the standard field equipment.

The high accuracy of the DMs allows recognition and interpretation of structures and features within a 3D-realistic scenario (ALFARHAN *et al.* 2008; BATES *et al.* 2008; OLARIU *et al.* 2008; SIMA *et al.* 2012; BUCKLEY *et al.* 2010,2013). However, the huge point clouds and the high quality of the model required to represent these type of dataset have been challenged in this knowledge area. The lack of integration between Geology, Geomatic and Computer Graphics has led researchers either to use non-specific applications to perform interpretations or to adapt interpretative routines considering the available software solutions that many times require discarding data or even applying techniques for reducing the number of points (ORYSPAYEV *et al.* 2012).

In-house computational systems have also been developed in the last few years by some research groups (BELLIAN *et al.* 2005; OLARIU *et al.* 2008; HODGETTS *et al.* 2007; FABUEL-PEREZ *et al.* 2009), in addition to commercial applications developed by both industries and universities (e.g., Polyworks®, Cyclone®, VRGS®, Coltop-3D®). They have been developed specifically to handle LiDAR data and to provide efficient visualization and navigation. However, the earlier systems are not available now, and the commercial versions are relatively expensive for academic purposes. Other options include free software (e.g.,

CloudCompare, LasEdit), but none of them have specific tools for interpretation. Thus, Outcrop Explorer was developed considering the need of integrating a well-known visualization technique with efficient data management and some editing and interpretation tools. It represents a specific application for visualization, manipulation, and interpretation of georeferenced point clouds. Differently of other works already developed, Outcrop Explorer intends to be developed of a collaborative way integrating facilities and tools of different area of knowledge. For attending this premise, it was based on free graphic solutions and proposed as an open source project. Moreover, all tasks necessary among the raw data and the visualization plus interpretation can be done within the same application which is based on a new workflow.

2. COMPUTATIONAL APPROACHES ON POINT-BASED REPRESENTATIONS

The point-based concept of scene building is a recurrent topic in Computer Graphics as well as in triangulated irregular networks (TIN). Levoy & Whitted (1985) initially applied this concept for rendering surfaces, and it has been investigated more in 2000's (ZWICKER *et al.* 2001; SAINZ & PAJAROLA 2004). The development of laser scanners capable to acquire million to billion points and their subsequent utilization for acquiring data from outcrops has made it necessary to develop solutions capable to handle this type of databases. The main challenge is to manage the huge amount of the data efficiently as well as to generate high-quality DMs. The traditional visualization techniques, such as TINs, are commonly used for rendering surfaces. However, our option in using point-based rendering is based on the nature of the database and computational performance.

2.1 Data structure organization

A common approach to organize data structure is hierarchical space-partitioning data (Levoy *et al.* 2000; Ren *et al.* 2002; Botsch & Kobbelt 2003). This model can be divided in two steps. First, different levels of detail (LODs) are created, in which on the highest level the object has its full resolution. In the second step the group of LODs is linked with the structure that organizes the space (Figure 1). Using different

LOD approaches, Sainz *et al.* (2004) compared the performance and defined how much data each approach could avoid sending to the graphic hardware as well as how fast they render the necessary data.

Another concept related with data organization is octree, developed and patented in the 1980's (MEAGHER, 1980,1982,1987). Afterwards, many scientific articles were published utilizing it for high-quality point-based rendering (REN *et al.* 2002; BOTSSCH & KOBELT 2003; PAJAROLA 2005; EBERHARDT *et al.* 2010). It is based on a hierarchical tree data structure in which each node can have either eight or no children. Each node can be divided more than once in eight parts, and so forth. This type of subdivision allows representing the 3D space as voxels. Partitioning, downsampling, and search operations on the point dataset are some of the resources allowed in this approach.

The standard algorithm for LOD is based on building different degrees of resolution and, at a specific moment, allowing the access only to the necessary data. The amount of data may depend on its application, like the viewer speed or distance. Luebke *et al.* (2003) presented a number of approaches and challenges for this technique, including a case study that used meshes as base. For the context of view-dependent LOD based on hierarchical spatial-partitioning of point clouds, the hierarchy is subjected to check the distance. Every time a node is defined as too close to the viewer, its children are brought to the same check, thus forcing more resolution to be displayed.

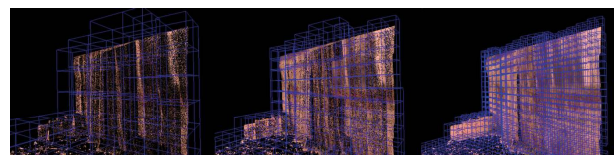


Fig. 1 - Example of hierarchical spatial subdivision of an adaptive point octree.

3. DESIGN IMPLEMENTATION

The starting point for developing this project was to find a solution for handling and interpreting large amount of the data acquired with laser scanners. A view-dependent LOD together with a spatially partitioned hierarchical

structure was the best choice in this case. The LOD concept along with the adopted octree structure allows sending of the only relevant data to the graphic card, and splitting of the access to the hard disk, which is a pain point in this process. This approach served as a base for the navigation and some of the tools built subsequently.

To properly define and document the steps required to analyze and process a DM, from the point clouds to the interpreted data, few workflows have been proposed (BELLIAN *et al.* 2005; ENGE *et al.* 2007; BUCKLEY *et al.* 2008; FABUEL-PEREZ *et al.* 2010; FERRARI *et al.* 2012) and one more is presented herein (Figure 2). Common steps involve data acquisition, processing, noise/obstacle editing, interpretation, and data exporting of the digital model. A common characteristic among the different workflows is the necessity of using different software products which are specific for different tasks. It increases the time of processing and interpretation, decreases the visual quality of the DMs in manipulation steps, and might face difficulties on data integration among systems.

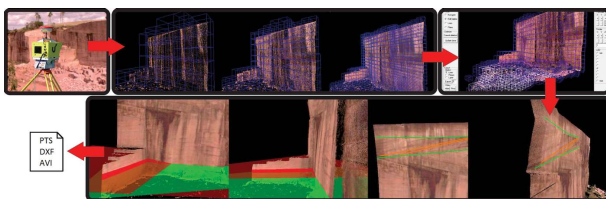


Fig. 2 - Logic workflow for view-dependent LOD used in Outcrop Explorer. It presents the logical sequence of tasks structured to optimize the handling and visualization of huge point clouds.

The necessity of a tool capable to integrate several steps of data acquisition and interpretation of a DM motivated this project. Outcrop Explorer is a software solution developed to process, edit, interpret, and export data and interpretations derived from LiDAR systems (Figure 3). The following requirements have been addressed: a) rendering of DM from LiDAR point clouds; b) manual noise/obstacle editing; c) manual interpretation tools such as lines and plane orientation, and d) data export. After having this structure as base, three modules were defined to split the entire process of handling the database: importing, navigation and editing tools.



Fig. 3 - Field data acquisition using a terrestrial laser scanner, processing, editing, interpretation, and exportation of a digital model based on point cloud.

3.1 Importing

This module reads the point cloud from a file, creates the hierarchical structure, and stores it on the disk. For storing the structure, the most used solution is simple file system. This option offers great possibilities, since it allows the developers to speed up the data reading in several ways.

The hierarchical space-partitioned structure used for this project is based on a simple octree. Each tree depth level is correspondent to a level of resolution built. Two processes, one for building the structure frame and other for building the LODs, are performed. The first process defines the number of layers or the hierarchical structure depth. Two values are used, the first is the smallest spatial cube based on a constant (which can be modified by the user) and the second is calculated based on the distance between the farthest points, which have the XYZ coordinates as comparison parameters. With these data, a giant cube is calculated. This cube should contain all points; and the size of its side is defined by the following equation (1):

$$BCS = (SCS) * 8L \quad (1)$$

(where, BCS = biggest cube size, SCS = smallest cube size, L = number of layers)

Once the biggest cube is defined, the space inside the cube is divided into eight divisions and each one is called child of the biggest cube. Again, each cube is divided into eight subdivisions and the process repeats until the number of layers is reached. Each cube

represents a node on the hierarchical structure. On a subsequent check, all the cubes that do not contain points inside their area are deleted from the structure with their children.

As a second process, the LOD is built by a bottom-up perspective. Firstly, the position of each point from the point cloud is evaluated. Based on its position, this point will be assigned to a node of the octree, which has an identifying key built with the power of 2 series (where x, y, and z use different powers). For storage, the application is built to work with the database (PostgreSQL) or system files.

3.2 Navigation

The displaying module operates after building and filling of the hard disk octree structure (Figure 4). The system builds an in-memory octree, based on a structure already created on the hard disk. But the point cloud is not yet exhibited. The behavior of the system is basically divided in two steps. One manages the data to be sent to the graphic card, whereas the other manages the data to be retrieved from the database. There is an initial data load from the database, that can take either small amount of the data or the entire database (depending on the size of the database). The user has the option of choosing which LOD will be used in the first data load, since specific tasks may not require much detail. Even though, it is recommended to use a level close to the maximum number of layers.

OpenGL was chosen as API to handle the overall communication with the graphics card interface. OpenGL offers all necessary tools to render the created outcrop model and has an extensive documentation available. A process using OpenGL updates the graphic processing unit (GPU) with the list of points currently on the main memory. The transmission of data from CPU to GPU memory is a possible bottleneck. Therefore, Vertex Buffer Object (VBO) was selected to converge the efforts. The usage of buffer objects enables great amount of the data to be transferred to the graphic card memory on a single call that is always made after changing the viewer position or the LOD parameter.

At the second step, if the required nodes are not in the main memory, which means they were not taken at the first load, the system looks for this information in the database. Since this access

is time consuming, a buffer environment is created. Each node accessed will have its points stored in the main memory, based on a default parameter which can be modified by the user.

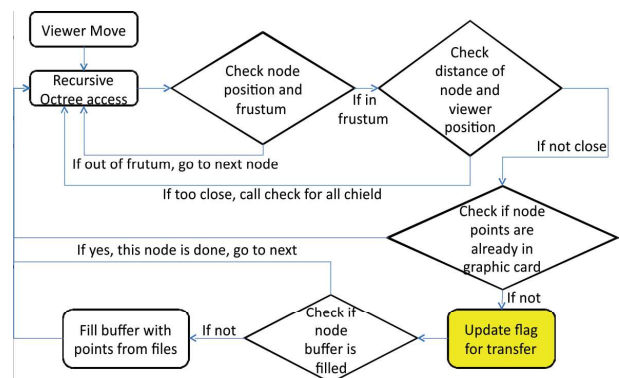


Fig. 4 - Outcrop Explorer’s visualization and navigation module. Note the high quality of the details of the rock face as evidenced by the zig-zag lines (stratifications) in the upper left corner of the point cloud, enhanced by weathering (darker areas of the wall).

3.3 Tools

After properly addressing the navigation, tools are offered to enable the geoscientists to interpret outcrops as presented in DMs. Most options require the ability of finding the place on OpenGL, respective to the place of mouse click. The most useful tools for this application are: to remove manually irrelevant data, to create lines, to create planes using three points as base and to export the interpretations in different formats, such as .dxf, .avi, and .pts.

3.3.1 Edit/Delete

During the acquisition by laser scanner, the presence of some types of obstacles, between the equipment and the target such as plants and random objects, is very common. This type of data is irrelevant but considerably increases the amount of the data to be managed in the database. To remove this unwanted information, an option was created using the octree structure. The user has the option to click at any point and the system identifies the current octree node to which the point belongs (Figure 5). Then, the user can remove this node and its children from the current visualization or it can be deleted directly from the database. However, the second option will also require a reconstruction of the

structure to remove the points from the parent nodes. This process can be done later and without affecting navigation and interpretation.

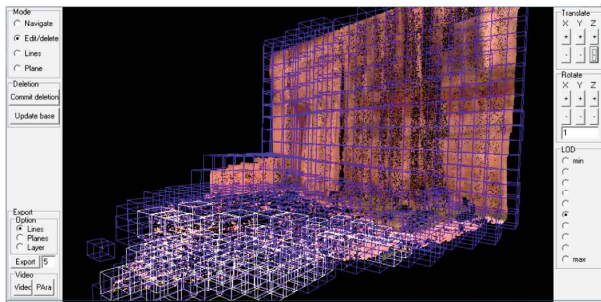


Fig. 5 - Digital model with the edition mode activated. Blue cubes are those that user may choose to delete. The white ones were manually selected to be deleted of the octree. Note that relevant data are in the vertical wall; the selected white cubes represent the floor of the quarry and other types of obstacles

3.3.2 Lines

With the option Lines, the interpreter can identify stratifications, beddings, fractures, faults, geometries and any kind of structures and features relevant for interpretation using mouse clicks on the screen (Figure 6). The tool also calculates the line size according to the coordinates.

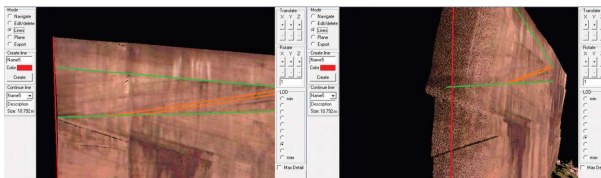


Fig. 6 - Interpretation lines revealing a cross-stratification directly on the digital model. Colors can be changed to enhance hierarchy or specific features. Note that lines are attached with the points as shown by the rotation of the digital model

3.3.3 Planes

Planes are almost always difficult to measure in outcrops due to the lack of good exposures in which geoscientists can take a great number of measures using a compass. In vertical outcrops, access to the upper levels is quite dangerous or even impossible. However, data from point clouds can easily provide a set of planes for the entire outcrop. Different

methods can estimate the orientation of planes from point clouds such as three points, planar regression, and inertia moment (SOUZA *et al.* 2013; GOMES *et al.* 2016). Outcrop Explorer is capable to create a plane using any three points on the screen (Figure 7). The software will define and show it on the screen with a transparent effect. Therefore, an option to set the north direction in the tool is also created; and, consequently, the spatial orientation of the plane is automatically calculated by the system.

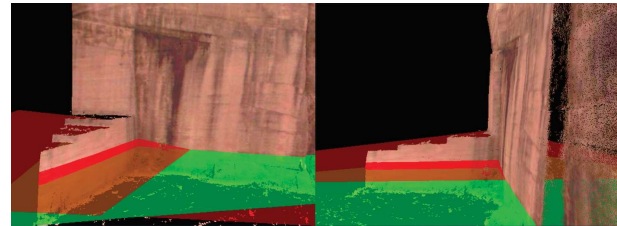


Fig. 7 Planes created from three clicks directly on the digital model. Note that green and red planes represent planes with different spatial orientations, in the case, a cross-stratification

3.3.4 Exporting

The system can export final interpretation in the form of lines, planes or any specific layer of the digital outcrop model as defined by the LOD. The most of the software products used for these purposes are not capable to handle a large database, especially the CAD-based applications. Thus, it seems to be a good option to export a layer from the DOM with low amount of the data after the interpretation.

For exporting, purposes, it allows creating PTS files, which can be imported in CAD or GIS-based applications. Another possibility for educational purposes or even for electronic publications is to export a video from the system. Currently, only short videos with less than a minute can be exported, since the system uses AviWriter that works with BMP images resulting in a large file size.

4. DISCUSSION AND FINAL REMARKS

Performance related issues were instantly addressed during the development. The database and system files, both were tested for data access. System files solution presented a faster data retrieval rate and was defined as the standard option, but for further developments, database can

be an interesting option in case of mobile access, therefore it remains available. Optimization on file access, such as data compression or stream of data storage, can provide performance boost. In this project, the files are stored from a binary memory stream representing a buffer of points, which reduces the processing time for each file. The files are simply transferred to a memory variable. Together with the view-dependent LOD, only the necessary data is sent to the graphic card after a movement of the mouse. But even this amount can be too much in a specific condition or may not be necessary for the user at a specific moment. Therefore, an option was created in which user can easily reduce the level of detail and raise it again at any moment during the interpretation.

The navigation with low-to-moderate resolution (until layer 8 of 11) did not show any delay, but at a very high resolution, it showed some delay in moments of buffering, which could be prevented most of the times by choosing the most suitable option among followings:

(a) Have a rapid navigation with relatively low resolution or have a temporarily slow navigation for inspecting details of the DOM with high resolution (in both cases all data of the point cloud are available in the database). For example, general measurements such as height and lateral extension, delimitation of rock body geometry and interpretation of line-based structures can be done with the first option (see Figure 6).

(b) To inspect a specific region of the point cloud or DOM with high resolution by removing temporarily lateral portions using the cube structure and working only with that specific region of the DM. This possibility can be used for detailed analyses, such as those involving inspection of high detailed features or structures and selection of specific points to define and orientate planes (see Figure 7).

The purpose of this project was to develop a specific system for geoscientists to visualize point clouds of outcrops and surfaces acquired with laser scanners and provide interpretation tools. Considering that many solutions for this type of application are present only as in-house developments, and that interpretation tools are not available in the most of commercial software products, Outcrop Explorer intends to be the beginning of a long-term project in which users

will be the main contributors for its development.

Performance in visualization will always be a big deal, since huge database is a prerequisite for digital outcrop representations based on LIDAR technique. New data management structures, high performance computing and new techniques for 3D visualization are required to improve the quality of a DOM efficiently, considering that new technologies on graphic computing arise daily. We have started a long-term project that, in this first approach, aims to provide a solution to visualize and perform basic geological interpretations in Digital Outcrop Models.

5. AVAILABILITY AND REQUIREMENTS

Outcrop Explorer is a free software developed for academic purposes. Its source code is open and researchers and users are invited to contribute with new solutions as well as to share them with the academic partners. It requires hardware configuration as follow: at least Windows XP, 2 GHz dual-core CPU, 2 GB RAM and OpenGL 1.5 GPU-enabled. If you want to download installer and related files as wells for technical questions, please contact gbellina@gmail.com.

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