Applications of Advanced Laser Scanning Technology in Geology

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Abstract

Laser Scanning or LiDAR (Light Detection And Ranging) was introduced to the engineering community roughly three decades ago which was only one real product: range data. As the LiDAR industry matured, the quality and capabilities of the technology has advanced. Some of these advancements include the integration of close-range photogrammetry, calibrated amplitude and reflectance, improved precision as well as full waveform analysis. These innovations are utilized for a growing array of applications in the geological field. A few examples include the combination of close-range photogrammetry and relative reflectance, advanced detection of weathering and the significant advancement in material classification via reflectance. It is the focus of this paper to demonstrate a few applications of these state of the art technologies in the geological field.

1 Introduction

The advent of 3D laser scanners brought about new methods of measuring volumes and examining physical features of the Earth. It has been possible to map and measure the Earth for hundreds of years, but due to 3D laser scanners, the speed and accuracy of mapping has advanced exponentially. It is now possible to take millions of precise measurements in seconds. *Riegl*'s laser Class 1 V-line scanners combine many advances since the emergence of 3D scanning to provide fast, accurate, and informative information. These key elements of the V-line scanners allow for many new areas of use to be explored. Several areas of focus that are only bringing to be explored by users in the field include weathering, and material classification.

2. Technology advances in LiDAR

New innovations in LiDAR technology have paved the way for additional information to be acquired simultaneously with each laser measurement. It is important to understand the innovations which make it possible to capture this additional information. Photogrammetry with LiDAR acquired concurrently gives an additional source of information for use in analysing surfaces, features and geological points of interest, (Tonon, 2006). Calibrated amplitude or reflectance allows for values to be decoupled from range allowing for materials to classified based on the relative reflectance information, (Pfennigbauer, 2010). Finally, online waveform processing allows for quick acquisition time with the added benefit of full waveform information, (Pfennigbauer, 2010). These technologies allow for increased information to be harvested from a single data collection, which can be used for analysing weathering, and material types.

2.1 LiDAR with close range photogrammetry

Camera systems can be tightly integrated with laser scanning instruments to create a powerful combination of imagery and dimensional measurement. The relationship of data between the two sensors can be calibrated to within a pixel of captured LiDAR data, (Sima.A 2010). The image is geo-referenced with the same accuracy as the scanner, resulting in millimeter precision on each pixel at close range due to the calibration between the laser scanner, and the camera system (Tonon et.al 2006). The symbiosis of these two sensors enables precision analysis and comparison of the two datasets, revealing information that may not be evident on each sensor independently. Historically this combination has been used in the field of geology by directly applying calibrated imagery to meshed point clouds to create a photorealistic virtual model (PVM) (Bellian et al., 2005; Buckley et al., 2008). An example of a geological PVM with significant features from Lionel White of Geological & Historical Models, LLC is shown in Figure 1.

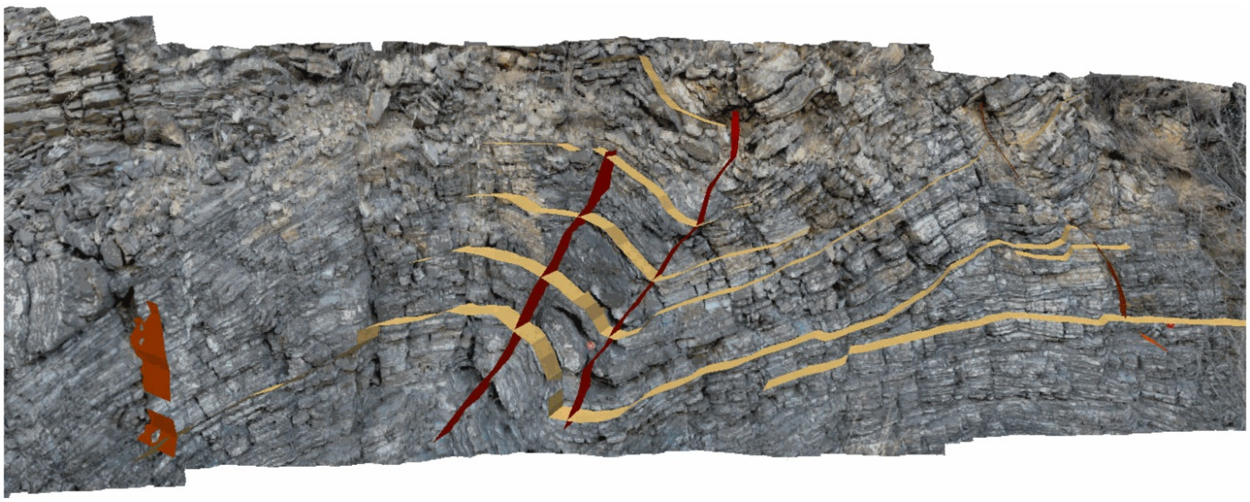

Figure 1. Photorealistic Model with 3D Geological Features (Courtesy of Geological & Historical Virtual Models)

A team from the University of Texas at Dallas (UTD) led by Professor Carlos Aiken is innovating new ways of applying this technology to the geological field. UTD is acquiring three dimensional data, high resolution imagery and combining them to create precise orthophotos referenced to PVMs. These orthophotos are then made available via the web, for geologists in the field to digitally mark and provide input in real-time with an online database of geological features. Figure 2 demonstrates how even small surface features, such as digging marks, due to the precise calibration of the camera lens to the LiDAR. Photorealistic modeling aids assessment of weathering, and material classification.

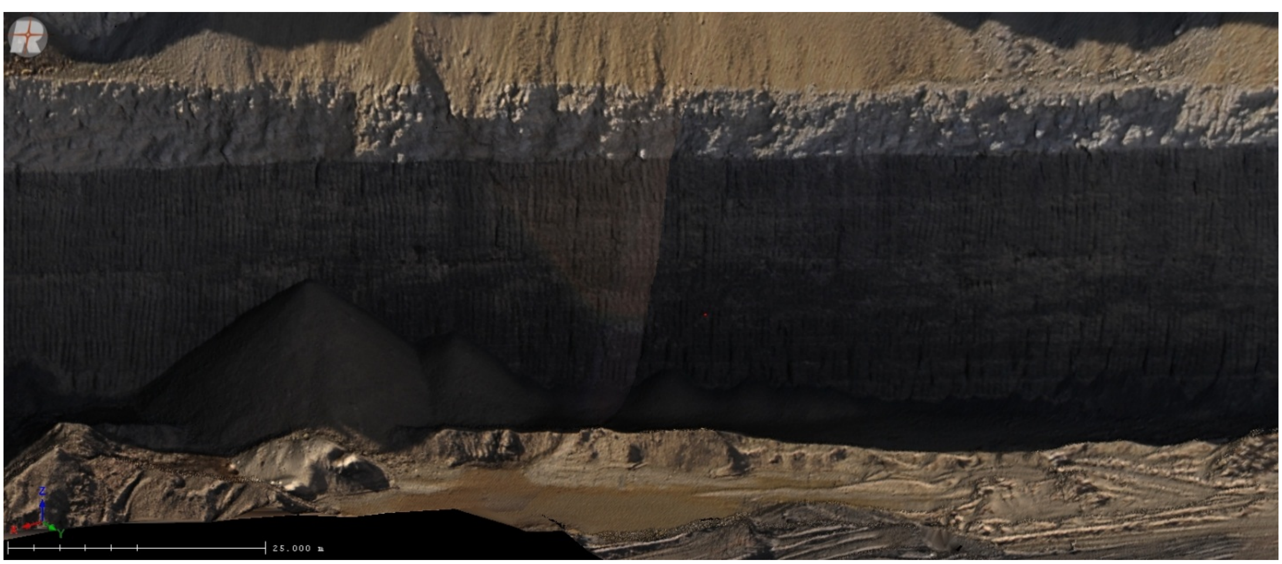

Figure 2. Close-up of coal mine high wall mesh coloured by RGB information from a Nikon D700

2.2 *Relative Reflectance*

LiDAR's first product is measuring range from light pulse returns. A secondary product is the returns amplitude, however amplitude measurements are range dependent. Amplitude values follow the $1/R^2$-law from the laser radar range equations when neglecting atmospheric attenuation, when considering the far field, (Jelalian, 1992). This is typically the case when taking scans of unstable wall faces. This dependence makes interpretation of the scan data difficult, especially when combining different scan positions at different ranges. Pfennigbauer et.al 2010 explain, by taking the ratio of absolute reflectance of the target to the reflectance of the target instrument, a value that is indifferent to the objects actual distance can be calculated. This allows for objects to be classified by relative reflectance.

2.3 *Online Waveform Processing*

V-line laser scanners use an advanced signal processing technology called online waveform processing. This technology enables full waveform analysis and rigorous multi-target detection to occur without further post processing of the data. The V-line scanners are sampling light between 42,000 to 122,000 measurements per second. Each laser pulse encounters multiple objects on its direct path, much like a narrow beam flashlight illuminates many branches in a tree. This technology allows for the calculation and logging of each object the laser beam encounters, Figure 3. The online waveform processing makes the determination between vegetation and ground echoes. A filter can remove vegetation based on target return time difference to reveal a bare earth.

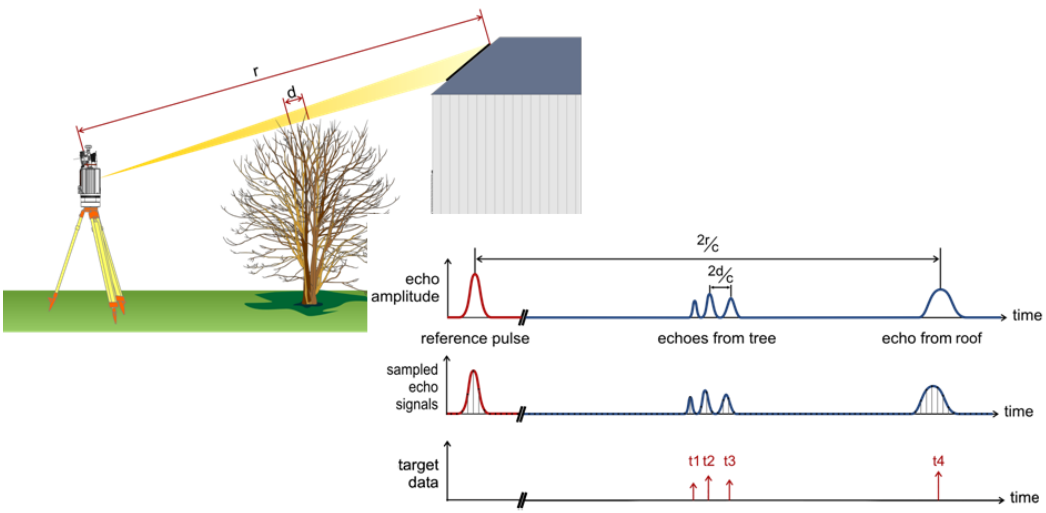

Figure 3. Online waveform single pulse explanation diagram

3 Applications

3.1 *Weathering*

The ability to assess the impact of weathering on slope stability is important to prevent the eventual failure on rock formations and mining excavations by determining the expected lifetime of the slope. LiDAR sensors to examine materials enable the ability to capture weathering effects that is otherwise difficult to determine visually. The degree of weathering can then be assessed through the intensity of the reflectance of LiDAR and the weathering rates can be determined. (Hack, R.) A simple demonstration of this difference can be seen by comparing a point cloud area of a high wall which is colorized by an image taken with a Nikon D700 (Figure 4) and the same point cloud area colorized by scaled reflectance taken with a terrestrial based LiDAR *Riegl* VZ-400 scanner (Figure 5). In Figure 4 it is possible to discern a slight change in colorization of the wall shown in the boxed area of interest. However, further inspection of Figure 5 reveals that the area of interest is highlighting a highly reflective material shown in red, whereas the surrounding area is seen in yellow. Thereby the area of interest demonstrates that fresh material in red has been pushed over the edge of the top bank and has spilled down along the wall. The capacity to collect reliable preventative landslide data and rock mass is vital in determining weathering information from LiDAR. (Strouth, A. et al).

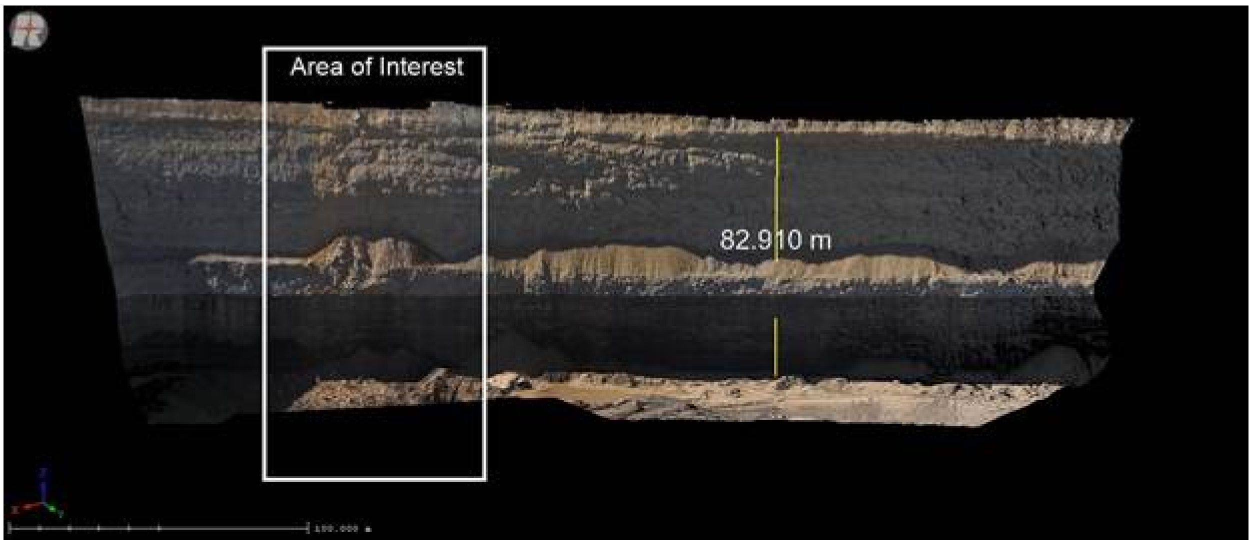

Figure 4. Coal mine high wall mesh colorized by close range photogrammetry (RGB) from Nikon D700.

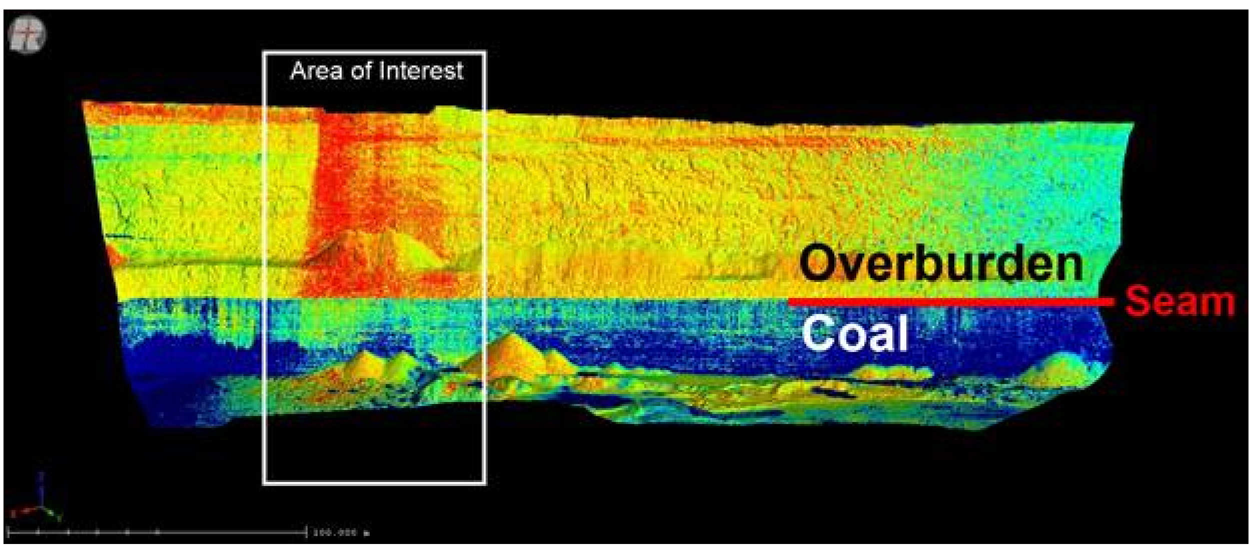

Figure 5. Coal mine high wall mesh colorized by relative reflectance from *Riegl* VZ-400 at a range of 160m.

An example of how online waveform is applied is shown in Figure 6 and Figure 7**.** A project 400 meters in length down a two lane highway lays in a heavily forested area was undergoing failure. This failure was caused by the subsidence topography of the slopes adjacent to the road. It was necessary to acquire data in this area for slope stability analysis. *Riegl*'s RiScan PRO LiDAR data acquisition and point cloud processing software was used in conjunction with the *Riegl* VZ-400 scanner. The software makes use of the online waveform by enabling the removal of vegetation, which allows for the generation of a bare earth model created from over 100 million points on site and in less than an hour. This enabled the analysis of the slope and watershed by using the Digital Surface Model seen in Figure 7.

Due to the high rate of scanning (122,000 measurements/sec) and online waveform technology, the team was able to map and model the site in 8 hours. This model clearly revealed the substance occurring to the highway. Traditionally a project of this stature would have required nearly one week of field surveying and three days of processing producing a topographic map with less than 1000 survey points. The benefit of LiDAR use is important to note in regards to the speed of data acquisition, processing time and ability to create models of the area for further analysis.

Figure 6. Aerial photograph of highway

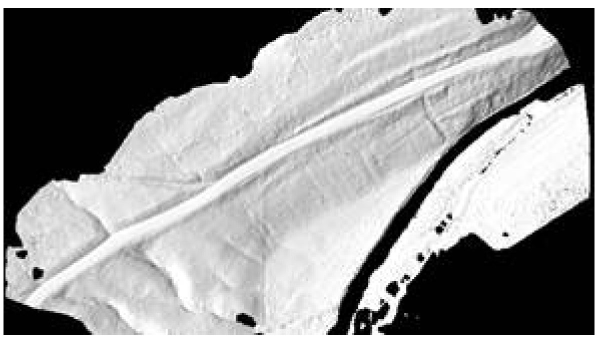

Figure 7. Digital surface model of highway

3.2 Material Classification

Relative reflectance enables discernment of material types from several scan positions. This capability is demonstrated in Figure 8, which depicts a coal mine high wall scanned with a *Riegl* VZ-400 terrestrial laser scanner from a range of 160 meters. The coal seam is visible due to the high contrast between coal (dark blue and the rock layer above it (yellow), Figure 8. Since, coal is back in the visible light spectrum it absorbs light, and a value represented by dark blue is -20dB. Pfenningbauer et.al (2010), calculate 100% reflective target returns 0dB and a dark gray diffuse target would result in -10dB, therefore it maybe concluded that a value of -20dB for coal fits this trend. Figure 4, is the colorized mesh of the same area, shows some black areas in the data but, the boundaries are not clearly defined due to shadowing, a weakness with photogrammetry, (Tonon 2006).

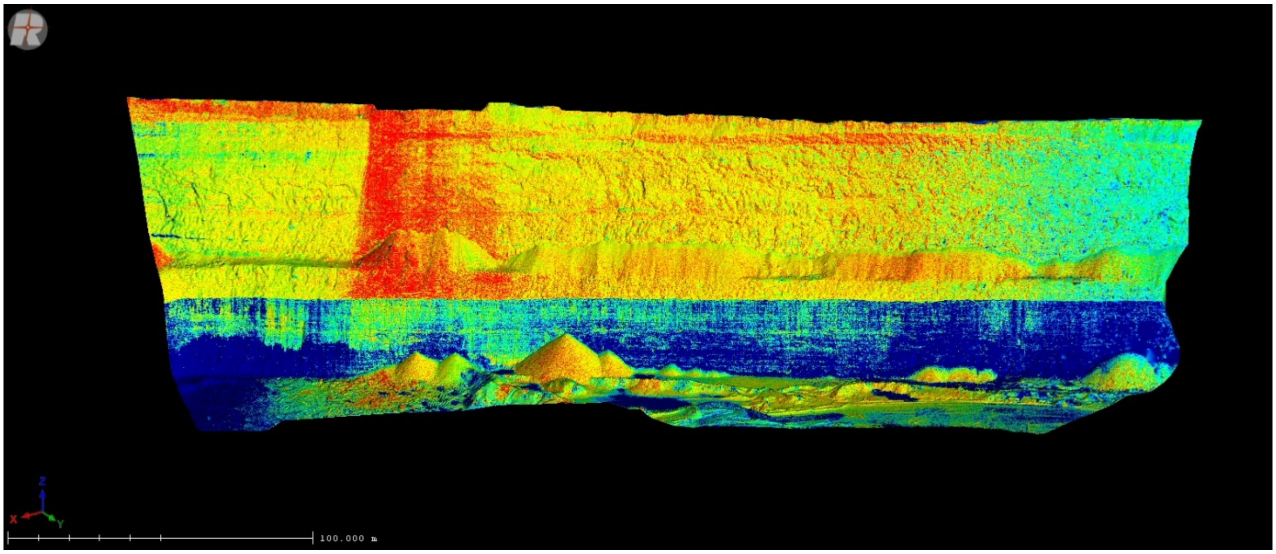

Figure 8. Coal mine high wall colorized by reflectance

This method of material classification is currently used in time sensitive situations where traditional methods would require too much time to efficiently operate. A high speed laser scanner can acquire a panorama of a scene within 5 minutes. The dataset can then be inspected and analyzed in an office environment which reduces errors and increases productivity. The material type of interest, once the relative reflectance value is determined, can be filtered to extract location information of a single material type.

4 Conclusion

While it is still possible to utilize LiDAR technology in a traditional manner for applications such as volume calculation and slope cross section analysis, there are innovations which enable a broader array of analyses. Close-range photogrammetry, when combined with LiDAR, enables advanced analysis of weathering and classification of material types in three dimensions. With scaled reflectance, it is possible to determine material types directly from the laser information as well as assess weathering. The increase in data acquisition rates and subsequent reduction of time to scan enables documentation of critical areas for time-sensitive applications. Online waveform analysis enables access to advanced scientific functionality for any user in the field to maximize range, precision and penetration of vegetation. LiDAR is moving from a survey instrument to a scientific instrument, capable of recording information far beyond ranges and angles.

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