ENABLING MINE AUTOMATION THROUGH THE APPLICATION OF NEPTEC'S OPAL AND 3DRI TECHNOLOGY

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ABSTRACT

In the mining industry there exists a constant drive for increased safety and productivity and decreased operating costs. This acts as a driver for implementing advanced technology. As more and more mining operations turn to new technologies, an observed bottle-neck for technology advancement has been the limitation of machine vision solutions available. LiDAR has been seen as a possible solution to the machine vision problem. In the past, a few studies on machine vision solutions have been undertaken by various groups involving scanning laser range-finders and millimetre-wave radar. These studies have done little more than highlight the limitations of both technologies in the mining environment. Little work has been done, however, exploring the applicability of LiDAR imaging technology for mining applications. Neptec Technologies Corp. has developed an obscurant-penetrating LiDAR (OPAL) sensor technology which overcomes the limitations faced by traditional LiDAR sensors when operating in a dusty environment, as well as advanced 3D real-time intelligence (3DRi) data processing algorithms that enable the real-time exploitation of 3D imaging data with sensors mounted on moving vehicles. Working with Teck Resources Ltd. and Barrick Gold Corporation, Neptec is adapting the OPAL sensors and 3DRi technology to mining applications. This paper highlights a number of real-time OPAL/3DRi based mining applications demonstrating how this technology overcomes the limitations of traditional LiDAR to provide a real-time machine vision solution that supports mine machine autonomy.

KEYWORDS

LiDAR, automation, mining, machine vision

INTRODUCTION

As the mining industry continues its rapid technological evolution, automation will become ever more crucial to the mine of the future. The leading mining companies are aware of this and have already started to prepare for this new reality. This industry-lead initiative can be seen on several levels and some examples follow. A working group comprised of some of the leading mining companies, equipment and technology manufacturers released a briefing paper which identified four priority initiatives – one of which was to maximize R&D efforts to offset the increasing demand, reduced quality of reserves and impending regulation pressures set to affect the industry (KIN Catalyst, 2012). A presentation by Rio Tinto's head of innovation at MinExpo 2012 outlined a vision for the mine of the future which was intimately tied to automation (McGagh, 2012). Also, a recently released report examining industry wide-trends further reinforces the growing appetite for automation in mining. This report highlighted the impending talent gap which could see a labour shortfall in highly active mining countries reach as high as 90,000 people per country by 2017 (Deloitte, 2013). The plans of many mining companies include an attempt to partially offset a labour shortfall by increased reliance on technology.

In addition to the points explored above, automation has been shown to be capable of addressing increased productivity requirements, allowing for an improvement in workplace safety, and facilitating significant gains through reduced maintenance requirements (Roberts et al, 1999), (Hwang, 1999), (Burger, 2006), (VSD, 2011).

While many signs point to an increase in the development and reliance upon automated solutions there remains a need for a machine vision product that can mimic and partially replace the abilities human operators often take for granted. Indeed, successful machine vision technology is often crucial in facilitating the ability to create an autonomous solution to replace a previously manned function (Tsugawa, 1994), (Rasheed, 2010), (Shen, 2010), (Meng, 2011).

For these reasons, a study was commissioned to evaluate the potential of a novel, obscurant penetrating LiDAR (known as OPAL) for use in applications related to mining. This LiDAR technology had been previously developed by Neptec Technologies Corp. for military applications. The study was jointly commissioned by Barrick Gold Corp. and Teck Resources Ltd. It took place over two field periods at an open pit mine site. Some of the data collected is explored in this paper. As well, two of several applications of interest are discussed in detail as is the final system solution which is currently under development by Neptec Technologies Corp.

MACHINE VISION FOR MINE AUTOMATION

Among the challenges involved in building a safe intelligent vehicle, localization is among the most important (Limsoonthrakul et al, 2009). Two widely attempted approaches to addressing the challenge of localization are the use of GPS devices and the implementation of wheel encoders. Unfortunately, both methods have their drawbacks. GPS devices, while extremely useful for localization, are not sufficient by themselves, because satellite signal quality varies with weather and proximity to trees and buildings (Limsoonthrakul et al, 2009). The problem has been seen to be especially acute in urban areas due to the presence of tall buildings, which translates directly to mining applications due to the depth of many open pit operations. The implementation of wheel encoders for the collection of vehicle odometry data allows for the correction of uncertainty that can be introduced by poor GPS coverage. The longer the localization system relies on odometry data in absence of GPS data the more position uncertainty builds. Once uncertainty grows too large the localization system must be recalibrated using a known landmark; machine vision is thought to be a good fit for this task (Limsoonthrakul et al, 2009).

Carnegie Mellon University, one of the pioneers in machine vision research, has been exploring constructive methods for autonomous driving using artificial vision for about two decades (Rasheed et al, 2010). In addition to its use as a position calibration device, machine vision yields a solution for the functions of obstacle detection and stand-alone navigation (Tsugawa, 1994). If an autonomous vehicle is to operate outside of a closed, controlled test track (such as a working mine site) the function of obstacle detection becomes a requirement. Previous work has shown that intelligent vehicles require a localization system that can operate at a frequency of 10Hz (and in some cases as low as 4Hz) to attain a safe working speed of 30 – 50 km/h (Limsoonthrakul et al, 2009), (Tsugawa, 1994).

When considering a mining application in particular, there are several other factors that lead to additional required functions for a machine vision based localization system. Paired with the previously discussed requirements, this list is as follows: must be capable of working independently of GPS for extended periods, must be capable of working independently of vehicle odometry data for extended periods, must operate at a high enough frequency to allow for required vehicle speeds, must not be affected by inclement weather conditions (dust, rain, snow, fog, extreme temperatures, etc.), and must be ruggedized for on machine, in mine use.

Although still in the development phase, the OPAL LiDAR paired with the 3DRi data processing package is thought to meet or exceed the requirements for use in mine automation. To determine if indeed this is the case, the aforementioned study was commissioned by Barrick Gold Corp. and Teck Resources Ltd., the results of which will be partially examined below. The technology used will also be discussed.

NEPTEC'S OPAL AND 3DRi

OPAL (Obscurant Penetrating Auto-synchronous LiDAR)

OPAL sensors incorporate Neptec's patented real-time obscurant penetrating LiDAR technology. Originally developed for helicopters landing in brownout conditions in the desert, OPAL is actually capable of penetrating obscurants such as dust, fog, rain and snow to dynamically image objects engulfed within those obscurants. Unlike conventional approaches to dealing with obscurants, such as range-gating or multi-echo technology, OPAL distinguishes between the LiDAR returns from obscurant particles versus objects of interest in real-time (no post-processing required). This technology works in near zero visibility conditions. This is thought to be a very attractive feature of this technology and a functional requirement for any machine vision which is to be relied upon in a working mining environment. This function acts to clearly differentiate OPAL from other LiDAR based technologies available.

Figure 1 compares the image captured by a conventional LiDAR device in conditions of moderate dust to the image captured by the OPAL device in the identical conditions. As illustrated, all that a conventional LiDAR device can see is the dust cloud itself. The OPAL scanner can, however, penetrate through the dust to see the target of interest (in this case the working dig face). This data was captured with an early prototype OPAL operating at a distance of 100m from the active face. It should be noted that the OPAL is capable of operating in near brownout conditions. Unfortunately, during both test periods, periods of extreme dust conditions were not witnessed.

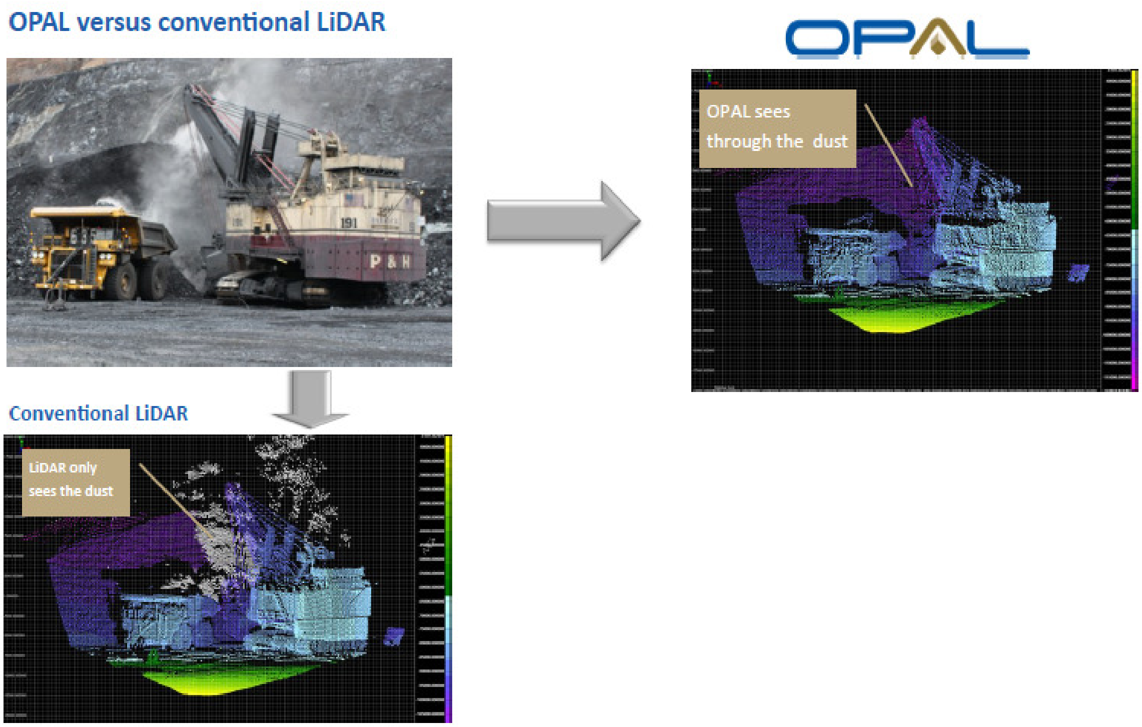

Figure 1 – Data showing OPAL dust penetration image compared to conventional LiDAR image

Figure 2 – OPAL-360 Sensor

Neptec has combined its OPAL technology with an innovative LiDAR sensor design to produce a compact, rugged, multi-purpose family of 3D sensors called OPAL 2.0. They have been specifically designed and packaged for harsh environments and real-time application. OPAL overcomes the two limitations of traditional LiDAR when used in harsh environments: the presence of obscurants and not being rugged enough to handle the harsh operating environment.

Based on an innovative sensor concept and patented obscurant-penetrating technology, Neptec's OPAL-360 (see Figure 2) is a versatile and powerful situational awareness 3D sensor for machine automation applications, as well as more traditional survey and measurement tasks. Unlike typical LiDAR sensors on the market, the OPAL-360 is environmentally sealed (IP67) with no externally moving parts, has a -40° to +65°C operating temperature range which is achieved with no fans or heaters for improved reliability, and is ruggedized to withstand significant vibration and shock levels.

3DRi (3 Dimensional Real-time Intelligence) Software

Traditional LiDAR systems are operated in a two-stage process that involves acquiring scan data and then post-processing the data to geo-reference it and to clean it up for analysis. Often the post processing step is time consuming. Neptec has developed the 3DRi software toolkit to accompany the OPAL-360 sensors to support real-time application of 3D data. The 3DRi software toolkit has been architected to allow for easy development and integration of next-generation intelligent machine vision applications that operate in real-time and from moving vehicles. In this way the OPAL will have the ability to act as a machine vision system while also collecting the background data for processing toward a different survey or mine monitoring application. The toolkit, illustrated in Figure 3, consists of a 3DRi System Manager, a 3DRi Viewer, and optional core and advanced components or plug-ins that deliver specific functionality.

The 3DRi **System Manager** is the basic framework for managing OPAL sensors and the scan data they produce. The System Manager provides a basic user interface for scan control and housekeeping functions. With the 3DRi System Manager, the OPAL sensor can be setup, scan parameters configured (such as field of view or scan pattern), scans initiated and the data saved in several different file formats. The 3DRi System Manager supports up to four OPAL sensors.

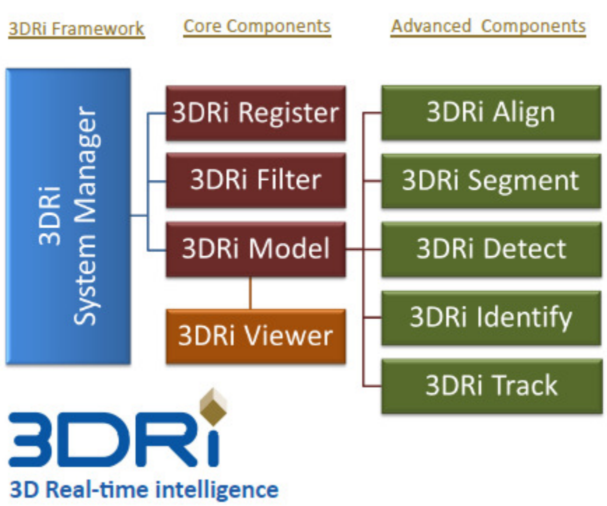

Figure 3 – 3DRi software building blocks

The **Core Components** are optional feature plug-ins for the System Manager that can provide enhanced functionality, including GPS registration of the scan data, control of the OPAL obscurant filtering mode, and generation of a 3D model from the scan data. All these features operate in real-time. The 3DRi Viewer is a graphical user interface which allows for visualization and manipulation of the 3D point clouds generated by OPAL.

The **Advanced Components** include proprietary algorithms for automatic scan alignment (without GPS or reference markers), data segmentation, automatic change detection and object recognition and tracking. This functionality meets and exceeds the two functional requirements for mine vehicle automation relating to working independently of GPS and odometry data. Using the OPAL-360 and 3DRi software, a localization system is capable of not just operating during short periods of no GPS coverage and large odometry uncertainty; the system does not require either as an input to accurately localize the vehicle's position. This is an attractive feature and makes this solution a good match for deployment towards an automated vehicle solution in a mining environment.

MINING APPLICATIONS

Operator-Assist Truck Spotting

Unlike traditional approaches to mine automation that create single purpose solutions that cannot be easily integrated or upgraded without deploying new or more capable hardware, Neptec's vision for mine automation is the deployment of a common 3D sensor infrastructure throughout the mine (on mine equipment and at stationary locations as appropriate) together with "at point of collection" intelligent 3D data processing to exploit the sensor data for local automation applications. By employing as much local processing as possible the burden placed on the mine site communication infrastructure can be kept as low as possible. Mine-wide data from the sensors and 3DRi local processing can then be consolidated via a wireless communications network to provide on-going monitoring of mine operations and performance.

In consultation with Barrick Gold Corp. and Teck Resources Ltd. a list of priority applications has been defined. Neptec is focussing its initial mining application development efforts on the highest priority item, which is a system that will aid haul truck drivers in positioning the haul trucks optimally with respect to the shovel. In addition, it is thought that the semi-contained, relatively slow speed application of truck spotting allows for a good starting point for mine vehicle automation and one that yields a higher probability of success and good rate of return for potential customers.

Figure 4 shows data gathered by a prototype OPAL-360 in an open pit mine that was positioned on the bench scanning an active face where a shovel was loading a single haul truck. The point cloud shows scan data that was captured over a 30 second period as the loaded truck left the shovel. Each of the truck positions in the scan data has been coloured individually to highlight them. In this instance the scanner was operating at 1/10 its maximum refresh rate of 30Hz, but still gathering more than enough data to track the path of the truck (shown here as the dashed white line). The position of the scanner is represented by the coordinate axes shown. The range from the scanner to the shovel (on the right and coloured orange) is approximately 100m.

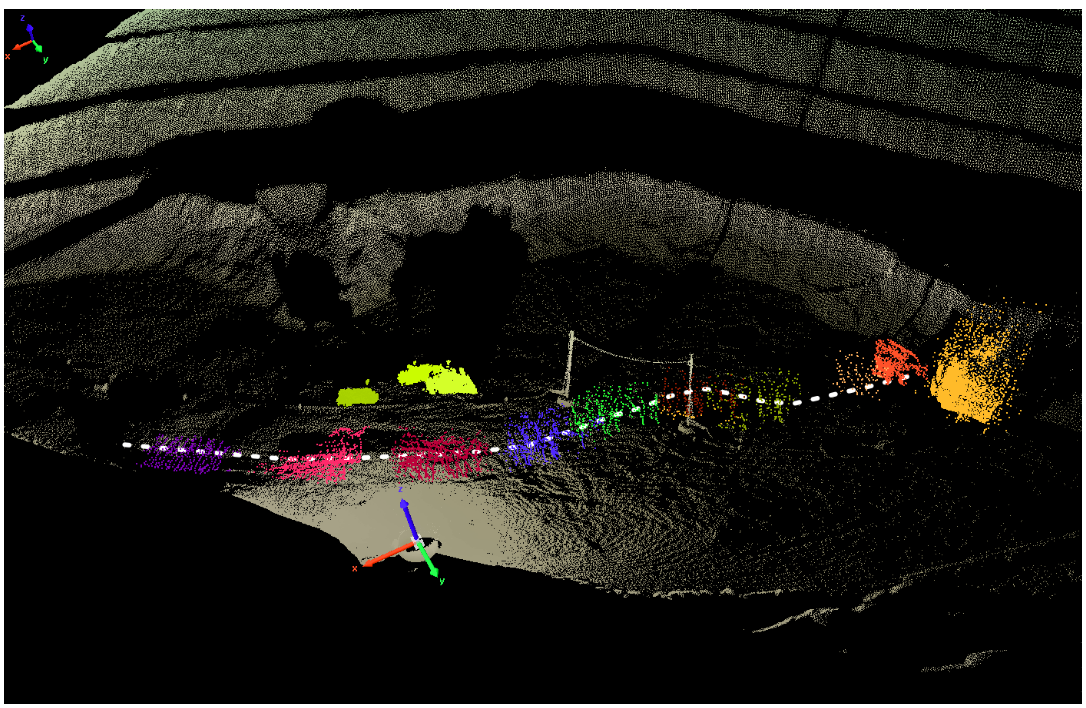

Figure 4 – OPAL-360 point cloud showing path of haul truck

The Operator-Assist Truck Spotting application is envisioned to consist of a shovel mounted OPAL sensor (or sensors) together with 3DRi software to identify and track approaching trucks. The output of the system will be positioning cues displayed on an in-cab display to aid the haul truck driver to stop the truck in the optimal location for loading at the shovel. Figure 5 graphically shows a typical dual loading scenario with the truck spotting system in operation. The shaded area represents the scan coverage from a single scanner mounted on the back of a shovel. The range of the scan data reaches up to 200m from the shovel. Shovel Position 1 (left) shows the shovel at the active dig face filling the dipper. Shovel Position 2 (right) shows the shovel filling the parked haul truck. The two images demonstrate how the scanner's field of view will regularly pass over additional areas of interest like the active face. This will be accomplished via the motion of the swinging shovel, thus gathering other potentially high value data that can be used for additional applications.

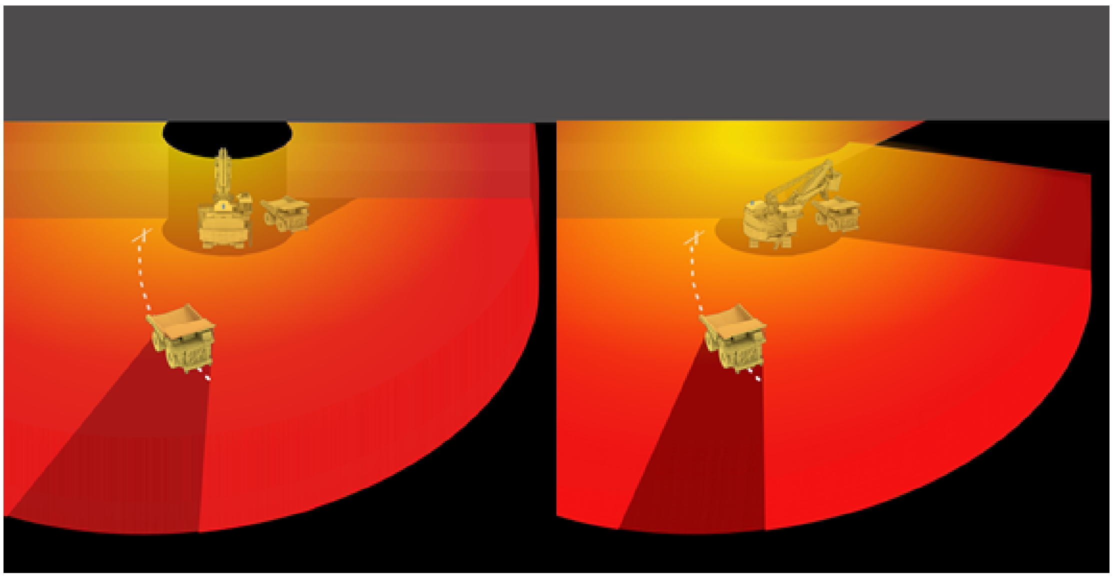

Figure 5 – Image demonstrating OPAL-360 scan coverage during operator-assist truck spotting

The Operator-Assist Truck Spotting application will be designed to support the spotting of two trucks simultaneously as well as managing the other types of vehicles typically present on a working bench. A typical use case for the application would begin when a truck is ready to spot, the haul truck software will issue a "ready to spot" message wirelessly to the 3DRi system running on the shovel. The signal identifies the truck to the Operator-Assist system and begins the spotting process. The 3DRi software then tracks the truck and calculates the path for the truck to follow to ensure the optimal position beside the shovel, taking into account any intervening obstacles. Low bandwidth data providing the optimal path is transmitted wirelessly from the shovel to the onboard truck software. This data updates the operator's display to pass along directional cues so that the operator can position the truck optimally at the shovel. The optimal position will be determined by the Truck Spot application using a combination of excavator dimensions, current working floor and face conditions, and specific shovel operator loading preference.

A more advanced version, using the same infrastructure, would eventually be developed for a fully autonomous solution. Instead of providing cues to an operator, the application interfaces directly to an onboard haul truck control system to provide the positioning information and vehicle commands to automatically guide and move the truck to its end location.

Fragmentation Analysis

Another potential application of interest is fragmentation analysis. This application can be deployed onto the same system that would run the Operator-Assist Truck Spotting application. Here the use case would be that high resolution fragmentation data is captured as a natural by-product of the shovel operation (and the Operator-Assist application). As the shovel swings to load the awaiting truck, the scanner will capture data at the active face. As the shovel swings back to the face for another pass, the scanner will capture the position, pose and volume of material in the bin of the haul truck (potentially another application relating to Load-Assist).

This data related to the working face would then be segmented out of the full data set as an area of interest for further examination. The raw point cloud data would then be handed off for fragmentation analysis processing. The processing flow would follow the steps outlined in the chart shown below in Figure 6.

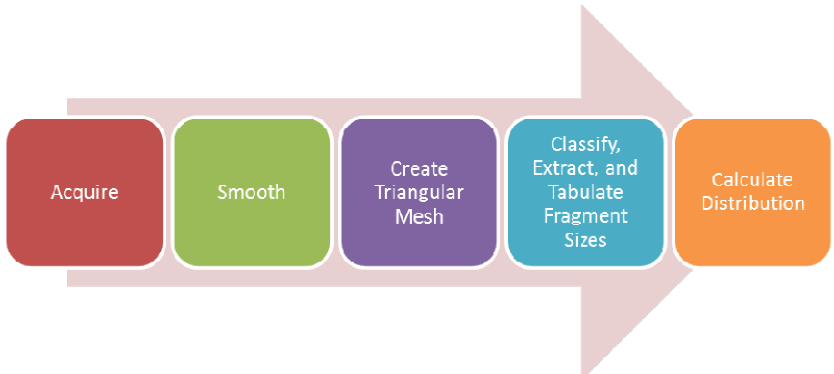

Figure 6 – Processing steps in fragmentation analysis algorithm

Figure 7 shows a picture of fragmented rock and the corresponding scan data that was processed through a prototype fragmentation algorithm. The output of the algorithm is a particle size distribution chart, an example of which is shown in Figure 8.

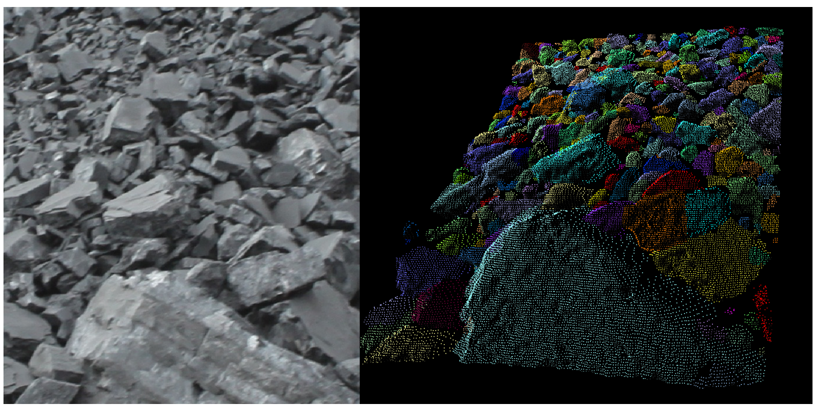

Figure 7 – Photograph and colourized fragmentation analysis point cloud

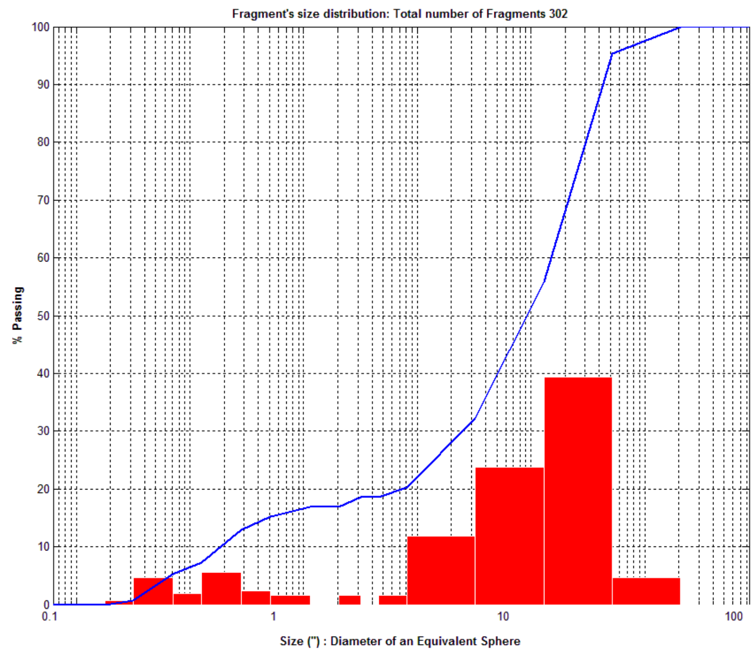

Figure 8 – Fragmentation size distribution plot of analyzed point cloud data

Although the data acquisition would occur in real-time, the generation of fragmentation analysis data would occur periodically at a pre-programmed interval dictated by the operating mine. The fragmentation data would also be referenced to the mine coordinate system and time stamped. This would allow for further analysis to be performed. This could include determination of the fragmentation profile and the potential diggability within a particular muck pile. This information would also be useful for future blast planning.

CONCLUSIONS

A machine vision product that can mimic the abilities of human operators is required for the automation applications that mining companies require to meet the increasing demands for productivity and to mitigate labour shortage issues. Neptec Technologies' rugged, obscurant penetrating OPAL sensor and 3DRi software toolkit meet or exceed the requirements to develop such machine vision systems. Neptec is working with Barrick Gold Corp. and Teck Resources Ltd. to demonstrate the abilities of the OPAL sensor and 3DRi software by developing an Operator-Assist Truck Spotting application that provides a system to aid haul truck drivers to position their trucks in the optimal location. A single deployment of an OPAL system provides the hardware and processing infrastructure to support additional applications to further exploit the data that is collected. One example of such an application is fragmentation analysis. Some additional potential applications include slope stability monitoring, stockpile volume monitoring, haul truck bin volume measurements, haul truck load distribution, road condition and berm height monitoring, real-time mine model updates, real-time muck pile geometry, obstacle detection, automated drilling.

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