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Post-Muckpile, Pre-Primary Crusher, Automated Optical Blast Fragmentation Sizing

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ABSTRACT

Automated rock sizing using digital image analysis has been well established. The methods work best under the controlled conditions of a conveyor belt, where camera angles and distances are constant, lighting is controlled, and sampling errors are at a minimum. Unfortunately, in most operations by the time rock is loaded onto a conveyor belt, it has passed through a primary crusher, and the size distribution no longer reflects only the blasting process.

   On the other hand, imaging and measuring the size of fragmentation on muck piles, while still useful, is problematic. Results can vary because of camera distances and angles, different lighting conditions can change measurements, and most importantly, because only the surface of the muck piles can be measured, tremendous sample bias can result in large measurement errors.

   The solution is to image the rock while in transit between the muck pile and the primary crushing station. This includes surface and underground HD (Haul Dump) and LHD (Load Haul Dump) type vehicles, using this method results in significantly decreased sampling errors. However new technical difficulties enter into the picture, including the need for advanced triggering and vehicle tracking mechanisms.

Keywords: Fragmentation analysis, sizing, particle sizing, granulometric, image analysis, process control, materials handling.

1. INTRODUCTION

Size distribution is a critical component of managing any mining operation, from the drilling and blasting to the final product; the material size dictates all downstream operating costs.

   Previously, the only way to measure a size distribution was to stop production, manually collect a sample, pass the sample through a battery of screens, weigh the material on each screen, and plot the data on a granulation curve to reflect what size the material was at the time of sampling. This method is slow, cumbersome, disruptive and not practical for the sizing of blasted material where the particles can range in size

from microns to meters. Even though sieve analysis offers a high degree of precision and accuracy within the sample, the sample size is traditionally very small making the results much less representative.

In 1987, the WipFrag photoanalysis system was developed to characterize the size distribution of blasted material. This system was the first of its kind (optical sizing system), and offered significant advantages over preceding methods such as speed, ease of use, and it was non-disruptive and practical for sizing any material which could be successfully imaged, including blasted material.

Ever since, photoanalysis has been used in a number of applications around the world, such as the analysis of muck piles, conveyor belts, surge bins, and most recently vehicle conveyances. This technical paper will describe the evolution of this technology as well as outline case specific applications of automated vehicle conveyance analysis.

1.1. Muck Pile Analysis

Automated sizing analysis of muck piles has been done for many years (Fig. 1). A review is given by Franklin et al. [1]. The WipFrag System (Fig. 2), first proposed in
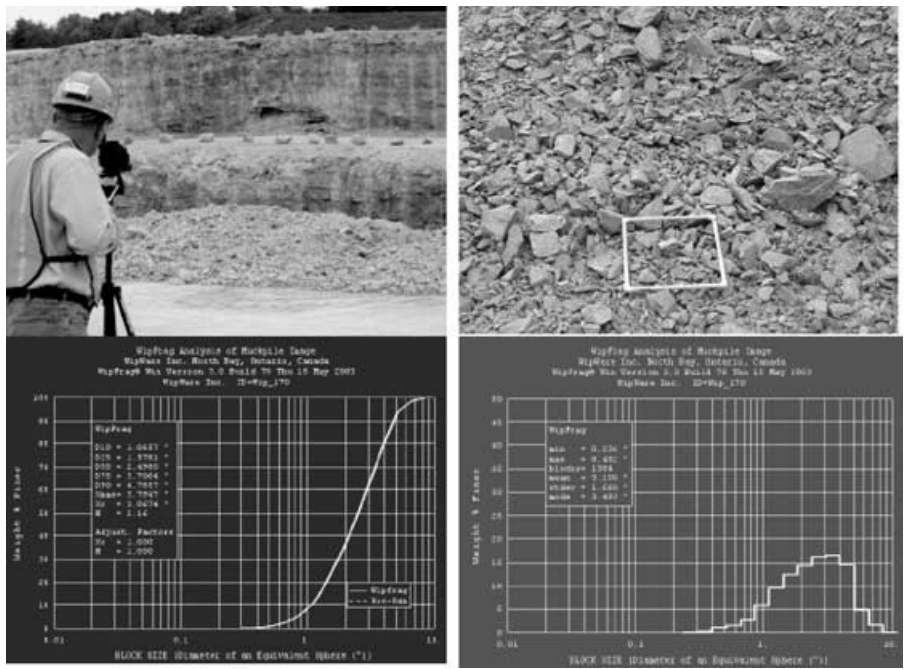

Fig. 1. Image of a muck pile taken and analyzed with a roving camera.

Fig. 2. WipFrag image analysis system.

1987 [2] and commercialized in 1996 [3], was initially used primarily to characterize the size distribution of muck piles. Various studies attest to the success of this approach [4–8].

Still, muckpiles are inhomogeneous, natural lighting conditions vary depending on sun angle and cloud cover, and camera angles can be quite variable. These and other errors were studied and quantified [9, 10]. From these studies the following factors were identified as most important in improving the accuracy of the measurements:

1. Consistent image quality, including uniform and constant lighting.
2. Fixed scale of observation.
3. Elimination of sampling biases.

Although consistent image quality, lighting, and camera position can be maintained with careful effort; the possibility of eliminating serious sampling biases when measuring muck piles is not great.
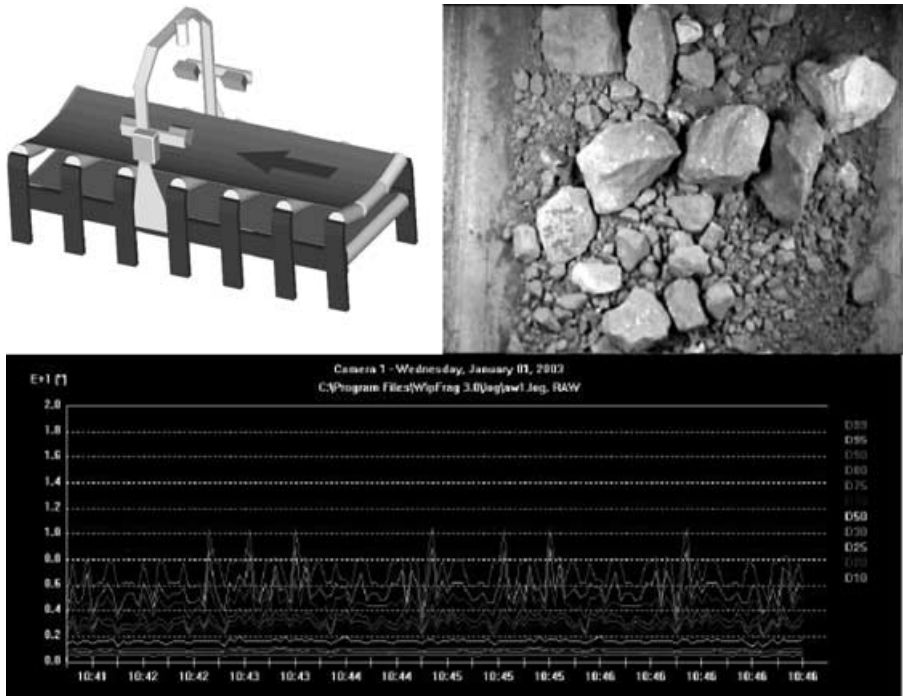
Fig. 3. Conveyor belt measurement set-up, images, and time based size tracking.

1.2. Conveyor Belt Analysis

Measurements made on conveyor belts (Fig. 3), by their very nature solve most of the above problems. Consistent image quality can be ensured by providing artificial lighting in a controlled environment. Constant scale of observation is guaranteed by fixed mounted cameras. Sampling bias are severely reduced because (a) all the materials is sequentially paraded before the camera, and (b) gravity segregation can be assumed to be constant and calibrated out. Various studies attest to the success of this approach [11–14].

The only difficulty in conveyor belt applications is that the blast size distribution has already been altered by primary crushing, since in most cases the conveyor systems begin only after the primary crusher.

1.3. Surge Bin Analysis

The surge bin to primary crusher set-up makes a good analysis point, only minor degradation of the material has occurred due to loading, haulage, and dumping. This

method also allows for moderate control over other variables such as lighting, scale and environment.

These configurations are very uncommon in the industry and are highly prone to jamming, which will introduce a unique error since the system will image the same material multiple times, biasing the sample.
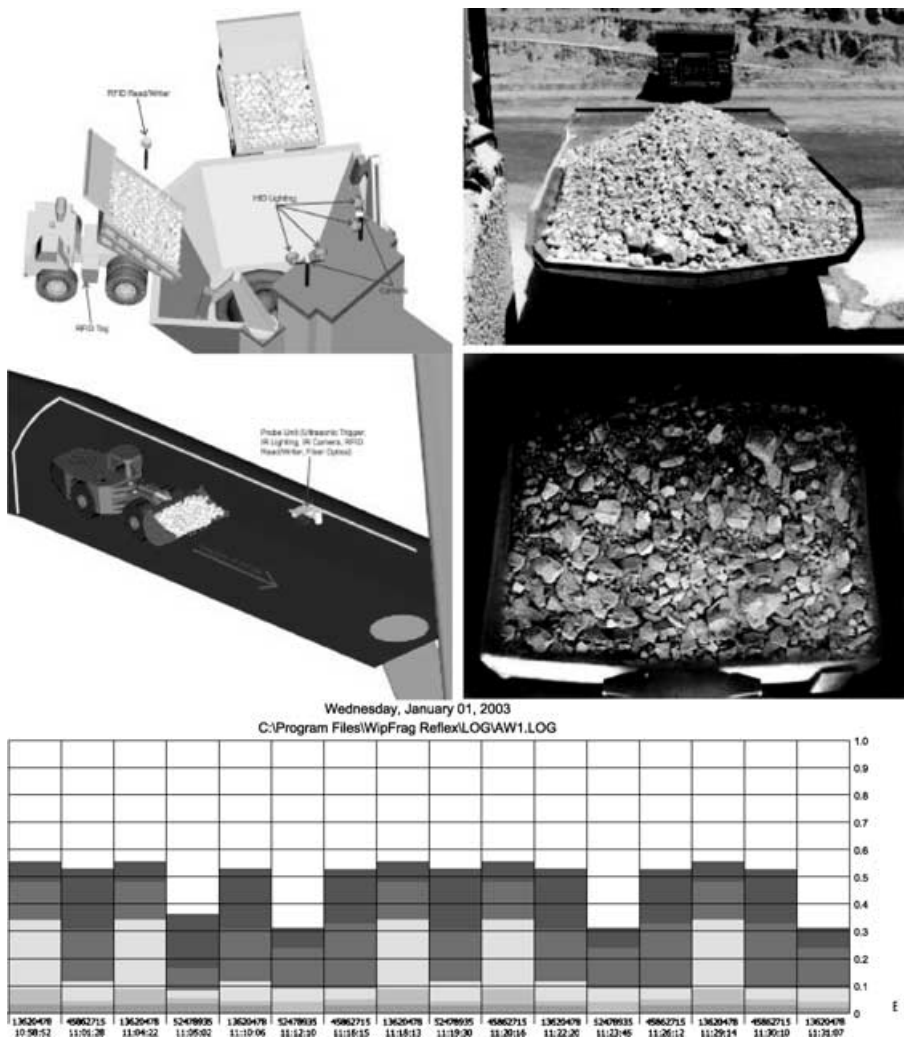

Fig. 4. In-vehicle measurement set-up, images, and time based size tracking.

1.4. Vehicle Conveyance Analysis

The best option then for automated analysis of blast fragmentation is to image and analyze the fragmented material in transit between the muck pile and crusher in the conveyance vehicles (Fig. 4). This implies both surface and underground HD type (Haul Dump) and LHD type (Load Haul Dump) vehicles.

2. TRUCK CONVEYANCE

Hundreds of case studies and years of data validate the WipFrag engine used to determine the size distribution of material in images; therefore there was no question of whether or not the material could be successfully analyzed in vehicles since this has been done manually for years. The real challenge was the design of an intelligent fragmentation analysis system capable of waiting for minutes, hours, or days for the presence of specific samples.

In 2001, WipWare developed a system specifically for this purpose, it was named WipFrag Reflex. By the final stage of development the system would exhibit near human qualities since it would need to execute many complex functions in order to obtain a suitable image for analysis such as:

1. "Sense" the presence of a sample.
2. "Wake up" from a dormant state.
3. "Identify" the vehicle and origin of material.
4. "Determine" whether or not the bucket is full or empty.
5. "Image" the bucket.
6. "Discard" any parts of the image that do not show rock material.
7. "Analyze" the image with an advanced fragmentation analysis system.
8. "Collect" the information in a comprehensive database.
9. "Share" the information over a network.
10. "Sleep" if no further activity is detected.

These complex functions would require significant expansion of sensory capabilities, breakthrough development of system logic and the tight integration of tracking technology with analysis results.

2.1. Triggering System

On conveyor belts with a continuous stream of material, timing of the imaging process can be left up to the software. When the software is ready for the next image, it can trigger an acquisition knowing that any image it takes should be adequate. The condition of empty or stopped belts can be signaled to the software using TTL (Transistor-Transistor Logic) signals, or using OPC (OLE for Process Control).

For imaging material in individual vehicles, no longer can the software sample on its own time; an advanced triggering system needs to be integrated into this system which would be responsible for multiple aspects of the image acquisition process.

The triggering system would need to meet certain criteria such as extreme reliability and durability, be waterproof and dust tight, provide adequate sensitivity at an adequate distance, be capable of operating in extreme temperatures, be easily contained, have low power consumption and be non-hazardous to personnel.

There are many types of triggering systems available; such as laser, ultrasonic, radar, microwave, IR beam, motion, pressure, optical recognition, and mechanical. Mechanical and pressure triggering was ruled out as a reliable triggering system since large and heavy vehicles would likely damage small, delicate contact type triggering devices. Laser and IR beam triggers proved to be oversensitive causing false triggers due to dust particles and other foreign obstructions. Radar worked well but was very expensive and posed health concerns. Motion triggering did not consistently trigger and the sensory area was not well contained.

Ultrasonic, microwave, and optical recognition type triggering have been integrated in the system. Ultrasonic triggering (Fig. 5) offers good range, is waterproof, robust and reliable even in harsh environments, offers large Mean Time Between Failures (MTBF), is safe and triggers consistently. Microwave triggering is very good in extremely dusty environments. Optical recognition triggering is used as a secondary triggering device, it utilizes the existing camera infrastructure by capturing
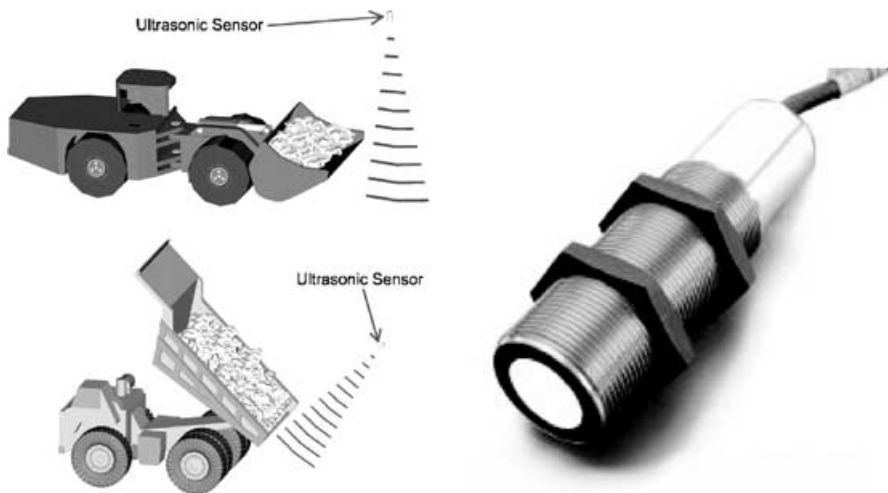

Fig. 5. Use of ultrasonic sensors, and close-up of an ultrasonic sensor.

multiple images and comparing them to each other, triggering only when a difference is detected over a given range of pixels (picture elements).

The tracking system (Section 2.2) can also be part of the triggering process, as it can be used to determine the proximity of the target vehicle.

2.2. Tracking System

In a typical mining application rock is transported from different parts of the mine, different rock faces or separate blast areas. Consequently the source of each truckload needs to be recorded to allow the system to merge the appropriate information.

The tracking system needs to meet certain criteria such as extreme reliability and durability, be waterproof and dust tight, provide adequate read/write speeds and range, be capable of operating in extreme temperatures, be easily contained, have low power consumption, not interfere with existing frequencies and be non-hazardous to personnel.

There are several types of tracking systems which will lend themselves to this criterion such as GPS (Global Positioning System); DGPS (Differential Global Positioning), Active RFID (Radio Frequency Identification), Passive RFID, Line Scanning (bar codes) and optical character recognition. GPS and DGPS were ruled out due to high cost, difficulty of integration, inability to determine exactly which vehicle is currently dumping at a crusher (in the scenario of multiple access crushers, because of limited resolution), inability to carry programmed information bits and suitability only for surface applications. Combined with previously collected field data, line scanning and character recognition were ruled out as a reliable method of tracking vehicles since it would require continuous processor usage, and would be subject to numerous read errors from dirty or obstructed bar or character codes on the vehicle. Passive RFID (Radio Frequency Identification) was initially very promising, meeting most of the required criteria, however limited write capabilities with poor read/write speed and low range (0.5 m or less) ruled out this method of tracking vehicles.

An active RFID type tracking system was chosen to be integrated into the WipFrag Reflex System (Fig. 6). Active RFID tracking systems offer excellent range (15 m), high MTBF, safety, low power consumption, and high speed consistent read/write performance which is both robust and reliable even in harsh environments. For this system to work, a single active RFID tag reader/writer is located in close proximity to the camera unit and lighting, making installation and maintenance simpler.

Various active RFID tag designs were tested for performance in both surface and underground mining environments. Since the RFID tag would need to be mounted to each vehicle, certain specifications were deemed important such as long battery life (∼10 years), low maintenance, low power, reasonably priced, hermetically sealed, resistant to oil water dust and impact, easy to mount, ability to work in proximity to
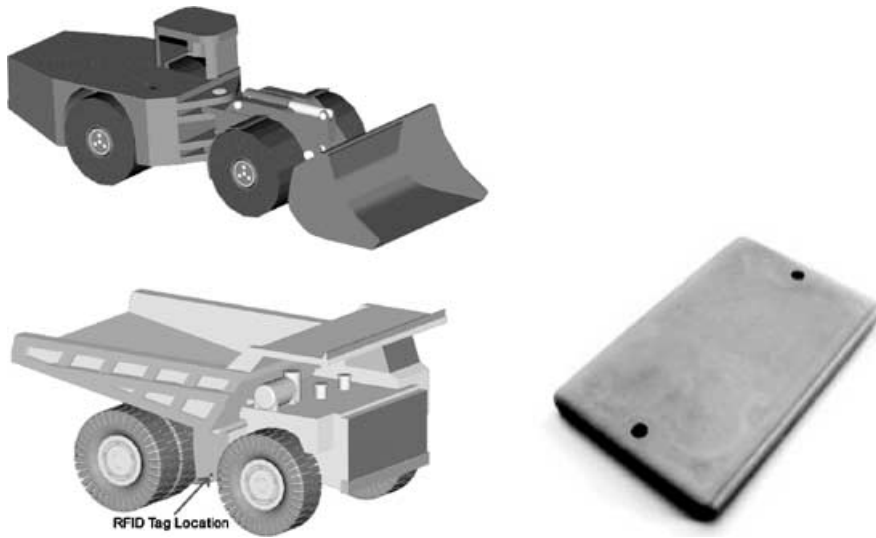
Fig. 6. Use of RFID (Radio Frequency Identification) tags and close-up of a tag.

magnetic ore types and be capable of being mounted directly to metal without seriously reducing the effective range. Although the need for a battery is a negative aspect of the active RFID tagging system, the long battery life and low RFID tag cost cancel out these issues. The active RFID tags used are considered a consumable item and are disposable.

The tagging system is then used to identify which truck is dumping and the knowledge base can tie the source of the material to the particular truck.

The tagging system also complements the triggering system. Since the tagging system can only identify a truck within a range of a few meters it can override false triggers when a valid truck is not present. This will reduce the chances of triggering on for example service vehicles.

2.3. Vehicle Positioning

On a conveyer belt the rock to be measured is always at the same place with respect to the camera. For muck pile sampling, images are selected by an operator. However when measuring rock in moving images (in an automated system) a problem that comes up is that the vehicle is not always in the same position. Consequently there is a possibility that any given image is not centered over the vehicle, which will result in erroneous measurements.

The solution is to capture the image at a point where the vehicle always passes a fixed point, or alternatively force the vehicle to drive into that position. In the case of truck tipping, a good location is the tipping station, since the truck is typically in the same position, and it is not moving at that point. For underground haulage, a good location is in narrow passes where the conveyance vehicle is naturally channeled into a narrow lane.

An intelligent image exclusion zone feature (a way of distinguishing between rock and objects such as the edges of the container) was required to ensure that only the rock material in the bucket or truck bed part of the image is analyzed instead of other items, such as the vehicle, ground or background (Fig. 7). This is because the edge detection algorithm will attempt to force edges onto everything on the image, including those of foreign materials.

2.4. Lighting System

On conveyor belts, adequate lighting is not difficult to attain since a relatively small area from a relatively small standoff distance needs to be illuminated. However, when
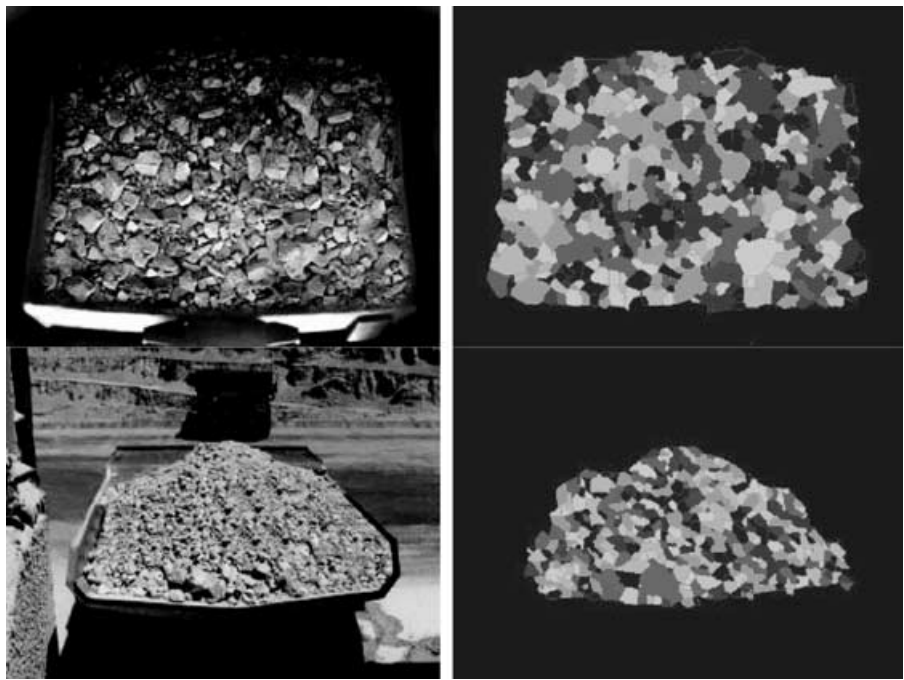

Fig. 7. Using an exclusion zone for a HD and LHD vehicle.

even illumination must be provided to negate sunlight effects on vehicles larger than a house under both day and night conditions or illumination of large conveyances in a pitch black underground environment other concerns arise such as lighting fixture cost, cost of maintenance, cost of operating and safety.

The lighting system would need to meet certain criteria such as extreme reliability and durability, be waterproof, dust tight, non-hazardous to personnel, capable of extreme temperatures, even provide illumination, provide suitable lumen output, bulb life, have reasonable power consumption, maintenance cost, operating cost, and not impair the vehicle operator's ability to maneuver the vehicle by blinding them.

There are many types of lighting systems available, such as fluorescent (including high frequency fluorescent and compact fluorescent), incandescent, halogen, visible LED (light emitting diode) array, infrared LED array, HID (High Intensity Discharge) type sodium and HID type metal halide. Fluorescent, high frequency fluorescent and compact fluorescent are some of the most efficient lighting types listed; however, they are not a practical illumination solution for this application due to high initial cost, expensive maintenance and delicate nature. The average bulb life of a fluorescent bulb is 8500 h and fluorescent lighting generates very little heat and may have difficulty starting in colder temperatures. Incandescent and halogen type lighting offer low initial cost but are plagued by high maintenance and power consumption costs: the average life of an incandescent bulb is 2500 h. While the average life of a halogen bulb is 2000 h, constant vibration will reduce these values significantly since the filament becomes brittle. Both of these lighting types generate an enormous amount of heat causing a potential hazard.

HID type sodium and HID type metal halide provide the best solution for surface applications, even though the lighting has a moderate initial cost, there are numerous advantages, such as a moderate operating cost, reasonably high efficient, resistance to vibration, long bulb life, and are generally well suited for outdoor industrial heavy duty environments. Although the average bulb life of a HID sodium bulb is 22 000 h, the light appears yellow which makes it less desirable. The average bulb life of a HID metal halide bulb is 13 000 h, and the color temperature is similar to daylight making it more desirable. Both lighting types generate some heat but it is not excessive.

LED array visible and infrared type lighting is the best solution for underground applications due to its extremely low power factor and resistance to environmental factors such as moisture, vibration, shock (concussion from blasting), dust and temperature conditions coupled with the longest average bulb life of all lighting types at 60 000 h (over 6 years of continuous use). LED type arrays are very light and have built in redundancy against lighting failure (if one LED burns out then there are a few thousand left). The disadvantage to this type of lighting is the initial cost, as these lighting types are somewhat expensive though not as expensive as intrinsically safe fluorescent lighting and the relatively low lumen output compared to other lighting types. The visible LED lighting may be disruptive to the vehicle operator (as would

Fig. 8. Metal halide high intensity discharge, and LED type infrared lighting sources.

any type of lighting), therefore, WipFrag generally use infrared sensitive cameras combined with the infrared type LED lighting, this lighting is completely invisible to any personnel or vehicle operators reducing eye strain. The infrared LED illuminator has a low power factor and considered no more dangerous to personnel than a couple of 100 watt light bulbs. Another property that the infrared type lighting has over the other types is its ability to cut through dust particles suspended in the air; infrared light tends to illuminate the subject instead of illuminating the dust particulate making this lighting type the best for the underground application (Fig. 8).

2.5. Other Issues

As mentioned earlier, dust, fog, rain, snow and particulates can be an issue if they obstruct the image. Infrared lighting in underground applications will eliminate much of the dust problem; however, surface applications usually have more difficulty with this issue. WipFrag is equipped with software image filters which require certain image quality criteria to be met prior to image analysis, this filter will discard any non-suitable images from a ''set'' taken from a tipping event, for example when a HD type vehicle approaches the crusher to dump, the system will take a preset number if images (usually 3–5) during the dumping process, prior to analysis it will audit each image to determine if the image characteristics are suitable for an analysis. If it is, the image is analyzed, if it is not, the image is discarded. What generally happens on dry days or where fine material is dumped the first few images get analyzed and the last few are discarded due to excessive dust. In the unlikely event that the system would discard all images, a log entry will be made and an error will be reported.

In some occasions where a rock breaker is used, it may obstruct the camera view, this cannot be helped, and every effort must be made to position the camera to minimize this issue.

3. CASE STUDIES

3.1. HD (Haul Dump) Type Surface Applications

3.1.1. Hamersly Iron Ore, Australia

The Hamersly iron ore open pit mine is in Australia. They are looking to reduce the number of fines and verifying this using optical analysis on tipping trucks (Fig. 9).

Two powerful quartz halogen lamps are used, one beside the camera mount, another from the side at an oblique angle. Imaging can only be done at night, as there is no shielding in place for direct sunlight.

Fig. 9. Truck tipping at Hamersley Iron Ore, Australia. Left: Early stage of dumping, little dust generation. Right: Later stage of dumping.

Because of the fines there is a tremendous amount of dust, and so a microwave trigger is used. It is located at the top of the primary crusher surge bin. The microwave beam is interrupted by the falling dumped rock, and sampling begins. In all, five images are taken at 2 s intervals, and then all images are analyzed. (After 10 s of dumping the images are generally too dusty to be useful). Results of all 5 images are merged into a single record (often the larger blocks appear in some of the later images).

Vehicle tracking is handled by the mine system using GPS, matching the truck movement with the timestamp provided by WipFrag.

3.1.2. Caluahusi Mine, Chile

The Caluahusi open pit copper mine is in Chile (Fig. 10). They are looking to track blast results for their mine to mill optimization study. WipFrag is capable of tracking these subtle changes easily at the truck tipping station.

Two powerful HID metal halide flood lamps are used for each of the two dumping positions at the primary crusher; a lamp is located to the left and to the right of each camera. The system operates 24 h a day mainly due to the predictable weather in the mountains; however, dynamic lighting conditions make night-time analysis the most reliable since there is no shielding in place to block direct sunlight.

Because of the lack of moisture, there is a significant amount of airborne dust during dumping. A laser trigger was initially implemented but since has been upgraded to a microwave triggering device which senses the presence of the vehicle commencing the sampling process. A cluster of 5 images are taken at 1.5 s intervals which are later analyzed and merged after the vehicle leaves the dump position.

Fig. 10. Truck tipping at Caluahusi Mine, Chile. Left: Before dumping, Right: during dumping.

Vehicle tracking is not used. GPS systems are present in the mine; however, the WipFrag system was initially installed at this site as a tool to achieve mine-to-mill data.

3.2. LHD (Load Haul Dump) Type Underground Applications

3.2.1. INCO Mines Research, Canada

The INCO research mine in Canada (Fig. 11) does not produce any minerals; its sole purpose is to test new technologies in a massive sulfide mine environment where controlled studies can be conducted prior to releasing new technologies into production mines. They are looking to control underground blast results as well as track their mine machinery; this data is in turn used for mine-to-mill optimization studies.

Underground configurations are safety oriented with two infrared light sources located on either side of the infrared camera in order to not blind the equipment operator. The integrated RFID tag reader/writer communicates data to and from the passing scoop tram, this information may include bucket full/empty, tag health, signal strength, battery levels, origin of material, and other useful production data including timestamp for each bucket dumped at the ore pass. The analysis results of the material which the scoop tram is conveying and all the images are saved for review at a later time. The system operates 24 hours a day; dynamic lighting is not an issue since the unit is located underground.

Dust and dirt obstructions are not a problem because infrared light has special properties regarding airborne particles, and an optional ultrasonic trigger may be used for additional control over vehicle image positioning.
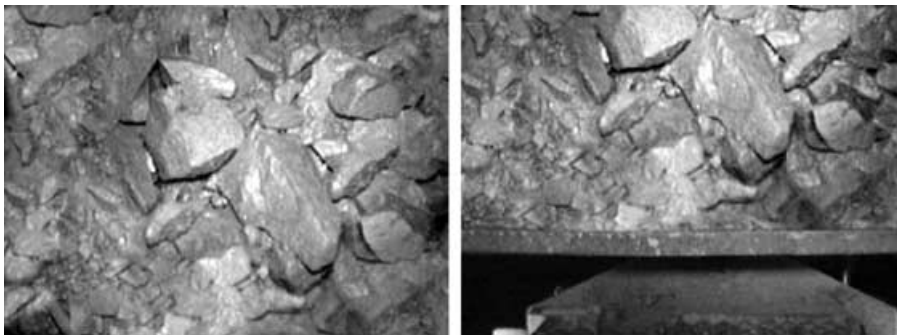

Fig. 11. Tracking ore at INCO Mines Research Canada. Left: Image captured correctly. Right: Image captured too late.

One to three images are taken at 0.2 s intervals which are later analyzed and merged after the vehicle leaves the dump position. Intelligent exclusion zones and filters discard images or analysis results that are unacceptable.

Vehicle tracking is used; RFID tags are placed on each scoop tram located in a safe position close to the front of the vehicle. The RFID tags are relatively inexpensive and are considered consumable and disposable items if damaged or if the battery dies. The average life of one RFID tag is approximately 10 years and is not dependant on the number of uses.

3.2.2. LKAB Kiruna Mine, Sweden

The LKAB Kiruna mine in Sweden (Fig. 12) is an underground iron ore mine, the largest of its kind in the world. They are looking to quantify underground blast results as well as track both manned and unmanned mine machinery. This data is in turn used for mine-to-mill optimization studies.

Underground configurations are safety oriented with two infrared light sources located on either side of the infrared camera to not blind the equipment operator. The integrated RFID tag reader/writer communicated data to and from the passing scoop tram. The system operates 24 h a day; dynamic lighting is not an issue since the unit is located underground.

Dust and dirt obstructions are not a problem, infrared light has special properties regarding airborne particles, an optional ultrasonic trigger may be used for additional control over vehicle image positioning.

One to three images are taken at 0.2 s intervals which are later analyzed and merged after the vehicle leaves the dump position. Intelligent exclusion zones and filters discard images or analysis results that are unacceptable.

Vehicle tracking is used; RFID tags are placed on each scoop tram located in a safe position close to the front of the vehicle. The RFID tags are relatively inexpensive and
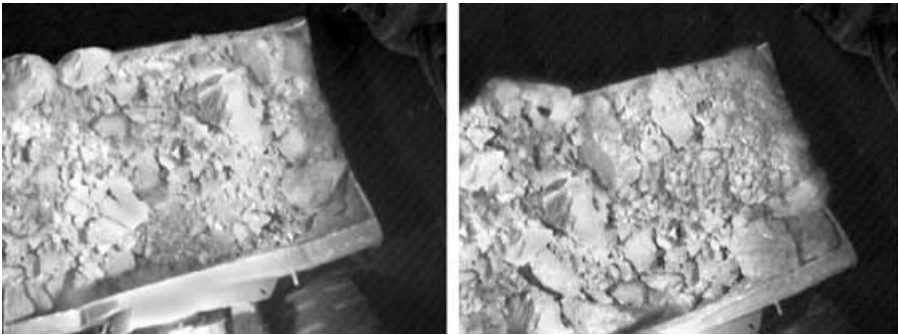

Fig. 12. Tracking ore at LKAB Kiruna Mine in Sweden.

are considered consumable and disposable items if damaged or if the battery dies. The average life of one RFID tag is approximately 10 years non-dependant on number of uses.

4. CONCLUSIONS

Recent experience has shown that with technological innovations, the size of blast fragmentation can be measured where it is most useful, in transit on haul trucks, after being removed from the muck pile, and before entering the primary crusher.

This required adapting optical image analysis programs to act on external triggering, developing a mechanism to provide that trigger, and developing a way to force the truck into the correct position for imaging without disrupting the routine of the truck or truck driver.

In addition, because mining is typically a complex operation, with simultaneous muck from various source areas, vehicle tracking is required, to tie each measurement to the appropriate database.

Other issues include lighting concerns and issues of automatic rejection of poor images because of obscurement by dust or stem (because no manual intervention is possible).

The cited case studies show that the methods described here are working and are in use in a number of facilities, they are being used to measure the optimization of the blasting process for each facility.

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