Brighton Conference Proceedings 2005, R. Holmberg et al
© 2005 European Federation of Explosives Engineers, ISBN 0-9550290-0-7

Advanced automatic optical blast fragmentation sizing and tracking

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ABSTRACT: Sizing of blast fragmentation using digital image analysis has proven an effective way to evaluate the results of blasting technique. Image analysis methods like WipWares's WipFrag system work best under controlled conditions like over moving conveyor belts, where camera angles and distances can be held constant, lighting can be controlled, and sampling errors can be kept to a minimum. However, once the fragmentation is on the belt, it has usually passed through a primary crusher and is no longer completely indicative of the blasting process. In practice, for many operations, this means that the best measurements can be made by imaging 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 which can be images as they dump, or prepare to dump, or as they pass through a gate or other restriction.

1 INTRODUCTION

1.1 *Optical sizing*

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 impractical 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 of optical sizing system, and offered significant advantages over preceding methods such as speed and ease of use. It was non-disruptive and practical for sizing any material that could be successfully imaged, including blasted material.

Since then, 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 describes the evolution of this technology into case-specific applications of automated vehicle conveyance analysis.

1.2 *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. (1996). The WipFrag System first proposed in 1987 (Maerz et al. 1987) and commercialized in 1996 (Maerz et al., 1996), was initially used primarily to characterize the size distribution of muck piles. Various studies attest to the success of this approach (Bartley and Trousselle 1998; Chiappetta 1998, Ethier et al. 1999; Barkley and Carter 1999; Palangio and Maerz 1999).

Still, muck piles 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 (Maerz and Zhou, 1999); Maerz and Zhou, 2001). From these studies the following factors were identified as most important in improving the accuracy of the measurements:

– consistent image quality, including uniform and constant lighting;
– fixed scale of observation;
– 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.

Figure 1. Image of a muck pile (bottom) taken with a roving camcorder (top); there is a scaling device in the foreground of the image.

1.3. Conveyor belt analysis

Measurements made on conveyor belts (Fig. 2), 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 material 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 (Elliot et al. 1999; Bouajila et al. 2000; Dance 2001; Maerz 2001).

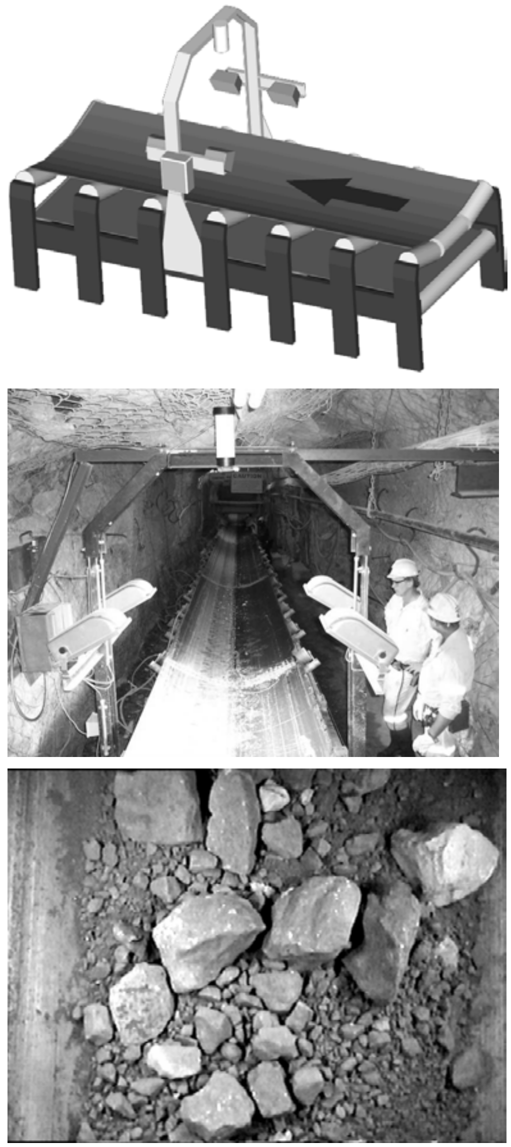

Figure 2. Imaging set-up of camera and lights (top and middle). Image of fragmentation on a conveyor belt taken with a fixed camera and fixed lighting mounted over a conveyer belt (bottom).

The 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.

1.4 Primary crusher feed bin analysis

The surge bin to primary crusher (Fig. 3) set-up makes a reasonably good analysis point, the material is representative of the blasting, 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.

There are several difficulties with this approach. 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. In addition, much of the time the bin sits empty or there is not enough material in the bin to do a proper analysis. This also introduces errors into the system.

Figure 3. Fragmentation in primary feed bin.

5.1 Truck conveyance analysis

The best option, therefore, for automated analysis of blast fragmentation is to image and analyse the fragmented material in transit between the muck pile and crusher in the conveyance vehicles (Fig. 4). This implies both surface and underground haul dump (HD) and load haul dump (LHD) type vehicles.

2 TRUCK CONVEYANCE MONITORING

2.1 Introduction

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 whether or not the material could be successfully analysed 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.

Figure 4. Image of fragmentation in back of truck (top) and in bucket of load haul (LH) vehicle (bottom).

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

- ‘sense’ the presence of a sample;
- ‘wake up’ from a dormant state;
- ‘identify’ the vehicle and origin of material;
- ‘determine’ whether or not the bucket is full or empty;
- ‘image’ the bucket;

– ‘discard’ any parts of the image that do not show rock material;
– ‘analyse’ the image with an advanced fragmentation analysis system;
– ‘collect’ the information in a comprehensive database;
– ‘share’ the information over a network;
– ‘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.

2.2 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 signalled to the software using transistor–transistor logic (TTL) signals, or using OLE for process control (OPC).

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.

Ultrasonic (Fig. 5), microwave, and optical recognition type triggering have been integrated in the system. Ultrasonic triggering offers good range, is waterproof, robust and reliable even in harsh environments, is safe and triggers consistently. Microwave triggering is very good in extremely dusty environments. Mechanical and pressure triggering was ruled out as a reliable triggering system, as large and heavy vehicles would be likely to 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.

Optical recognition triggering is used as a secondary triggering device; it utilizes the existing camera infrastructure by capturing multiple images and comparing them to each other, triggering only when a difference is detected over a given range of pixels (picture elements). Optical recognition triggering on its own is normally not adequate.

The tracking system (section 2.3) can also be part of the triggering process, as it can be used to determine the proximity of the target vehicle.

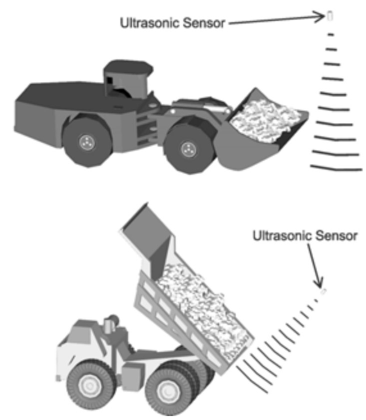

Figure 5. Use of ultrasonic sensors to determine the presence of material, either being transported (top) or dumped (bottom).

2.3 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.

There are several types of tracking system that will lend themselves to this criterion such as global positioning system (GPS); differential global positioning (DGPS), active radio frequency identification (RFID), passive RFID, line scanning (bar codes) and optical character recognition. GPS and DGPS were ruled out owing 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 as 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 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. Active RFID tracking systems offer excellent range (15 m), low power consumption, and high speed consistent read/write performance that is both robust and reliable, even in harsh environments. In addition, the tag can dynamically store data, such as the weight or source of the material.

A single active RFID tag reader/writer is located in close proximity to the camera unit and lighting, and an optional tag writer can be put in the area where mucking is taking place, to identify the source of the material. On the truck is a tag (Fig. 6) which has a long battery life (10 years), low maintenance, is reasonably priced, hermetically sealed, resistant to oil water dust and impact, easy to mount, has the ability to work in proximity to magnetic ore types and be capable of being mounted directly to metal without seriously reducing the effective range.

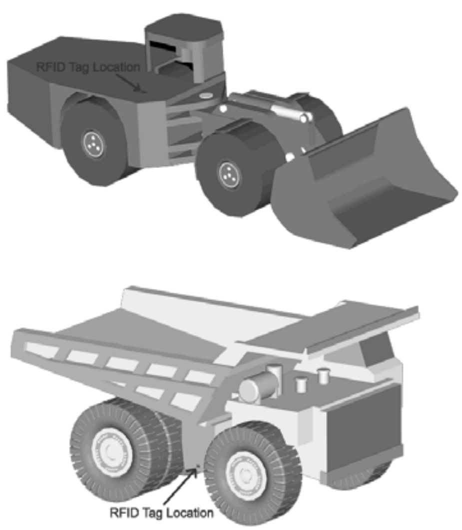

Figure 6. RFID Tags on vehicles.

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.

2.4 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, image positioning is done 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 as the vehicle always passes a fixed point, or alternatively force the vehicle to drive into that position (Fig. 7). 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 channelled into a narrow lane.

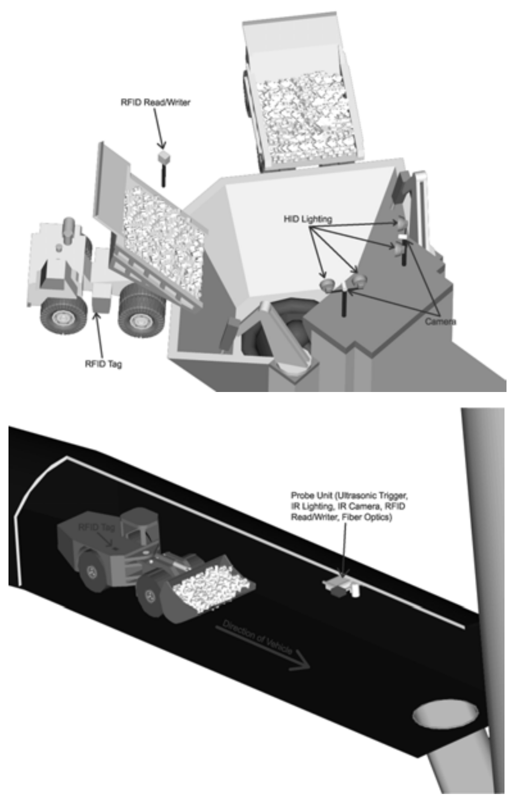

Figure 7. Camera, lighting, and RFID tag reader set-up in a position to force trucks into the correct position to be imaged.

2.5 Image limit detection

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 analysed instead of other items such as the vehicle, ground or background. This is because the edge detection algorithm will attempt to force edges onto everything on the image, including those of foreign materials.

2.6 Lighting systems

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 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.

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 moderate operating cost, reasonably high efficient, resistance to vibration, long bulb life – and are generally well suited for outdoor industrial heavy duty environments. The average bulb life of a HID metal halide bulb is 13000 hours, and the colour 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 owing 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 – 60,000 hours (over six 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 disadvantages to this type of lighting are 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 any type of lighting); therefore, infrared sensitive cameras combined with the infrared type LED lighting are used. The infrared LED illuminator is low powered and considered no more dangerous to personnel than a couple of 100 W lightbulbs. 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.

2.7 Environmental Conditions

Dust, fog, rain, snow and particulates can be an issue if they obstruct the image or the triggering mechanism. 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 that 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 an HD type vehicle approaches the crusher to dump, the system will take a preset number of 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 analysis. If it is, the image is analysed; if it is not, the image is discarded.

Variable daylight conditions serve to confuse the image analysis sequence. Light intensity variations, sun angles, superstructure shadows, and differences between natural and artificial lighting all serve to create small differences in the analysis results. Solutions range from shielding the material from direct sunlight or operating at night only to accepting the errors.

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 HD APPLICATIONS

HD applications are typically used in surface mining.

The Hamersly iron ore open pit mine in Australia is looking to reduce the number of fines and is verifying this using optical analysis on tipping trucks (Fig. 8). 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.

Because of the fines, there is a tremendous amount of dust, a microwave trigger is used. 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 analysed. (After 10 s of dumping, the images are generally too dusty to be useful).

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

Figure 8. Truck Tipping at Hamersley Iron Ore, Australia; Early stage of dumping.

At the Caluahusi open-pit copper mine in Chile, they are looking to track blast results for their mine-to-mill optimization study (Fig. 9).

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 hours a day, mainly owing 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 has been upgraded since to a microwave triggering device that senses the presence of the vehicle commencing the sampling process. A cluster of five images are taken at 1.5 s intervals and are later analysed and merged after the vehicle leaves the dump position.

Figure 9. Truck tipping at Caluahusi, Chile.

4 LHD APPLICATIONS

LHD applications are typically used in surface mining.

The INCO research mine in Canada (Fig. 10) does not produce any minerals; its sole purpose is to test new technologies in a massive sulphide mine environment where controlled studies can be conducted prior to releasing new technologies.

Underground configurations are safety oriented with two infrared light sources located on either side of the infrared camera so as not to 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 system operates 24 hours a day; dynamic lighting is not an issue since the unit is located underground.

Dust and dirt obstruction is not a problem because infrared light has special properties regarding airborne particles, and an optional ultrasonic trigger is used.

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

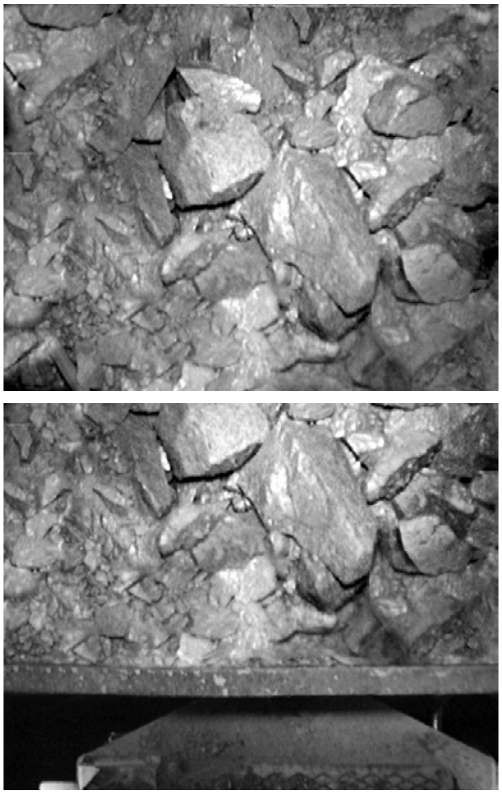

Figure 10. Sequence of images at INCO. Top: well-timed image. Bottom: image taken too late.

The LKAB Kiruna mine in Sweden (Fig. 11) 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 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 hours a day.

One to three images are taken at 0.2 s intervals which are later analysed 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.

Figure 11. Tracking Ore at LKAB Mine.

5 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 (because no manual intervention is possible).

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

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