Planetary & Terrestrial Mining Sciences Symposium, NORCAT, Subury, June 9-11, 2004, 6 pp.

Imaging Process Control for Mining and Comminution of Construction Materials

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Keywords

Fragmentation, Image analysis, Sizing, Process Control, Particle sizing, Granulometry, Materials handling, Mining software, Blast analysis.

Abstract

Extraterrestrial mining activities will at first be concerned with the production of construction materials. Rock and earth materials can provide the strongest and most cost effective solutions. Scarce resources (energy, human intervention) in extraterrestrial mining operations, will limit many types of activities.

At the same time, construction materials need to be processed, including blasting, crushing, screening, and milling, to exact specifications. Automation is the key to minimizing resource utilization, and optical sizing is crucial for these tasks, enabling automated process control without requiring excessive human quality control strategies.

1 Introduction

Some of the first extraterrestrial mining activities will be the acquisition of construction materials. Much more so that on earth, the most cost effective materials are those native materials that can be mined as close to the construction site as possible. As on earth, rock materials will serve to build the most cost effective and strongest structures.

In extraterrestrial mining operations, resources will be scarce. Energy reserves will be limited, so mechanical activities need to be minimized. Human activity and intervention will be minimized because the additional requirements for energy, oxygen, water, and food will place severe restraints on the number of personnel available.

At the same time, construction materials need to be extracted and processed to meet fairly exacting size standards in order for them to perform their designed function. Extraction may involve at first scooping up regolith, but eventually will require drilling and blasting. Processing may include crushing, screening, and perhaps even milling. Rock products need to have specified size distributions and shape properties, and comminution processes need to make these size distributions with a minimum amount of expended energy.

Optical sizing technology such as WipFrag can help with both these tasks. Optical sizing can determine if the size/shape parameters are correct. Optical process control can make possible real time adjustments to comminution processes, so that time and energy are not consumed making defective product.

The only alternative to optical sizing/processing control are automated mechanical sizing devices which would be prohibitively expensive to transport to the site, and present a maintenance nightmare or extensive human quality control strategies that would require at the very least additional personnel, subject to hazardous duty.

2 Optical Sizing

Size distribution is a critical component of managing any mining operation, from the drilling & blasting to the final product; the material size dictates all downstream operating costs. The alternative is to use manual screening, which even on earth is a slow, cumbersome, and disruptive procedure, and is not at all practical for the sizing of blasted material, with their relatively large block size.

In extraterrestrial blasting application size control will be even more important, because there will undoubtedly be very little that can be done with oversize fragmentation, as secondary breakage effort would be extremely uneconomical. In addition there will not likely even be equipment large enough available to transport the oversized pieces out of the way, resulting in impeded mucking, drilling, and blasting operations.

2.1 Historical Development

Automated sizing analysis of muck piles has been done for many years (figure 1). A review is given by Franklin et al. [1]. The WipFrag System (figure 2), first proposed in 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],[5],[6],[7],[8].

This approach requires digital images used to measure particle size distributions, images that can be taken from either roving cameras on a robotic vehicle, or from high resolution surveillance cameras which should be pre-existing infrastructure common to all remote mining equipment.

Figure 1: Imaging blasted rock.

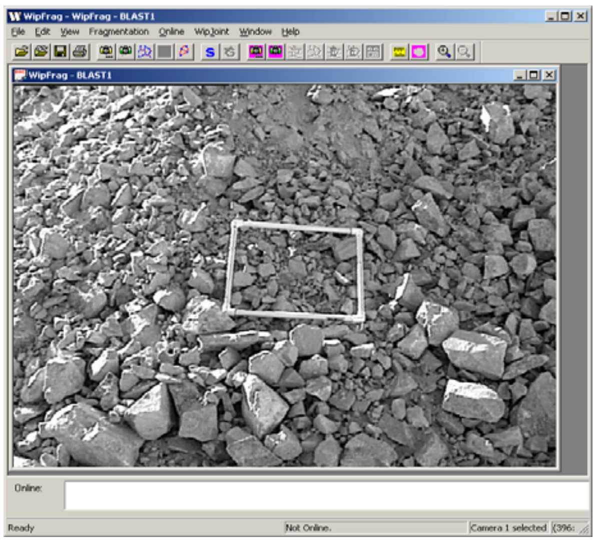

Figure 2: Image to be analyzed.

2.2 Automated Online Applications (Conveyors)

Measurements made on conveyor belts (figures 3, 4) to determine material size distributions using the WipFrag Momentum system, by their very nature give consistency in lighting, camera angle, and scale of observation. 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 biases 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 [9],[10],[11],[12].

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, so they do not reflect measurements of blasting results.

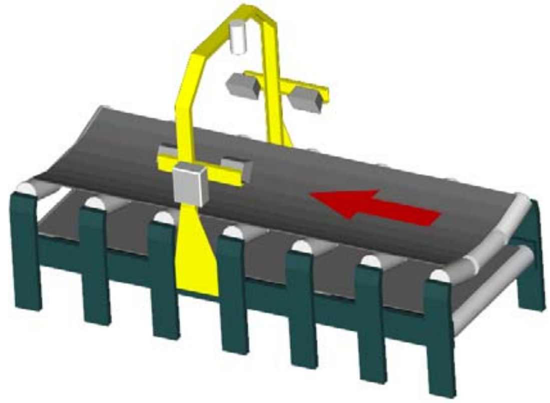

Figure 3: Conveyor belt setup with camera and lights.

Figure 4: Conveyor belt image.

2.3 Automated Vehicle Conveyance Applications

The real challenge of mobile conveyance applications 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 [13], named WipFrag Reflex (figures 5, 6). By the final stage of development the system exhibited 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.

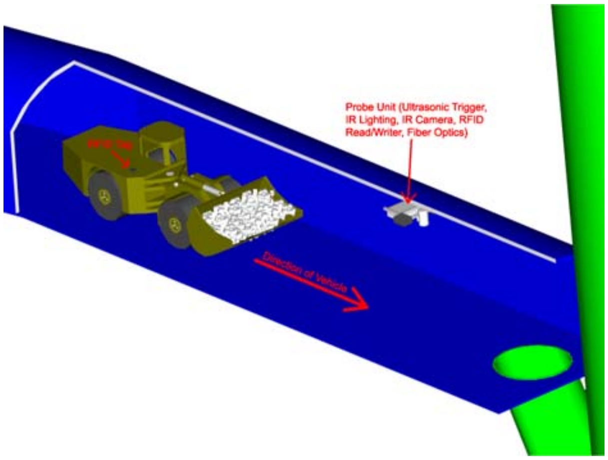

Figure 5. Vehicle conveyance setup.

Figure 6. Loader bucket image

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

These very challenges resulted in a product that could be utilized in an extraterrestrial environment where most everything would need to be automated.

3 Technologies for Extraterrestrial Mining

Many of the technologies used in the WipFrag Reflex system are conducive to extraterrestrial environments. Components are used that have long time life spans, low power consumption, and automated operations.

3.1 Triggering Systems

For imaging material in individual vehicles, no longer can the software sample on its own time; an advanced triggering system needs to be used

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 were ruled out 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 (figure 7, 8) offers good range, is waterproof, robust and reliable even in harsh environments, offers large Mean Time Between Failures (MTBF), is safe and triggers consistently however this sensor type would not work in a vacuum where sound cannot travel. Microwave triggering is very good in extremely dusty environments, this sensor type should be capable of operating well in both atmospheric and vacuum environments. 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).

The tracking system (section 3.2) can also be part of the triggering process, as it can be used to determine the proximity of the target vehicle.

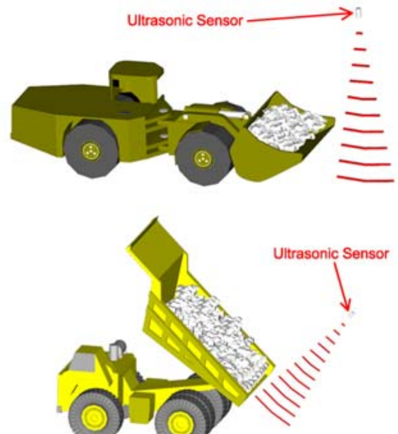

Figure 7. Ultrasonic trigger sensor setup.

Figure 8: Ultrasonic trigger sensor.

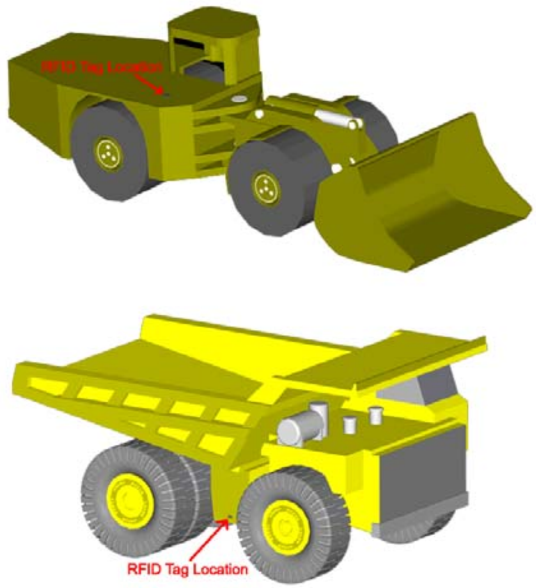

Figure 9. RFID tracking system setup.

Figure 10. RDID transmitter.

3.2 Tracking Systems

In typical mining applications the source and movements of each truckload need to be recorded.

A tracking system needs to meet certain criteria such as extreme reliability and durability, be dust tight, provide adequate read/write speeds and range, be capable of operating in extreme temperatures, be easily contained, and have low power consumption.

In extraterrestrial environments GPS (Global Positioning Systems) may or may not be available. Barcode scanning or character recognition was 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 barcodes that could not easily be cleaned in an extraterrestrial environment

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 meters 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 (figure 9,10). Active RFID tracking systems offer excellent range (15 meters), high MTBF, safety, low power consumption (~10 year battery life), 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.

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.

3.3 Lighting Systems

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, provide even 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 practical illumination solutions due to high initial cost, expensive maintenance and delicate nature.

The average bulb life of a fluorescent bulb is 8500 hours and fluorescent lighting generates very little heat but has 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 hours. While the average life of a halogen bulb is 2000 hours, constant vibration will reduce these values significantly since the filament becomes brittle. Both of these lighting types generate an enormous amount of heat, resulting in energy waste.

HID type sodium and HID type metal halide provide 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. Although the average bulb life of a HID sodium bulb is 22000 hours, the light appears yellow which makes it less desirable. The average bulb life of a HID metal halide bulb is 13000 hours, and the color temperature is similar to daylight making it more desirable. Both lighting types generate some heat but it is not excessive.

Figure 11. High Intensity Discharge (HID) Metal Halide Flood Lamp.

Figure 12. LED type infrared lighting sources.

LED array visible and infrared type lighting is the best solution for many 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 60000 hours (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). 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. This is important where electro-statically charged dust is a big problem.

3.4 Software Error Checking

Error checking built into software is an excellent solution to problems because there is no overhead in terms of equipment (weight), energy costs, or on-site repairs.

Software error checking in WipFrag includes diagnostics to determine the quality of the image. If it is too dark or too light, images are rejected. (Too dark can be indicative of malfunctioning lighting.) If the variability in lighting intensity is too low, then the image is rejected. (Low contrast images are indicative of dust obscurement or images of backgrounds rather than rock samples).

4 Conclusions

Extraterrestrial mining of construction materials will have a considerable amount of special requirements, most notably low consumption of resources, and functionality in hostile environments.

Many of the features being put into terrestrial mining applications will also be useful for extraterrestrial mining. These include the need to work in hostile environments, be totally automated with error correction, and have components that have long lifespans before needing maintenance or replacement.

Other issues will have to be considered anew, such as the extreme costs for delivering large equipment, the difficulty providing service and spare parts, and the considerably more hostile environment.

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