Rock Fragmentation Analysis using UAV Technology

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In recent years, UAV (Unmanned Aerial Vehicle or "Drone") technology has been introduced into the mining environment to conduct terrain surveying, monitoring and volume calculation tasks. These tasks are essential for mining operations, but they do not leverage all of the benefits that UAVs can offer to the industry. In general, UAV technology can be used for acquisition of any kind of high-resolution (aerial) data, which can be beneficial in blast design, mill operations, and other mine-to-mill process optimization campaigns. Moreover, compared to traditional and typically manual measurement techniques, data acquisition with UAVs provides higher spatial- and temporal-resolution data, which improves the statistical reliability of measurements. One of the novel applications of UAVs in mining, being studied at the University of Toronto, is the real-time measurement of rock fragmentation.

Continuous measurement of rock fragmentation is essential for many mining operations. Production blasting in mining operations acts to reduce the size of rock blocks so that the rock can be transported from an in-situ location to downstream mining and comminution processes. The rock size distribution induced by blasting influences the efficiency of all downstream mining and comminution processes, including: loading, hauling, crushing, and grinding. It has been shown that rock fragmentation can influence the volumetric and packing properties of the rock (e.g., the fill factor and bulk volume) and, consequently, the efficiency of digging and hauling equipment. Similarly, it has been demonstrated that the rock size distribution fed into the crushing and grinding processes has a direct impact on energy consumption, throughput rates, and the productivity of these processes. Due to these impacts, the measurement of post-blast rock fragmentation is an important metric in the optimization of a mining operation. Furthermore, real-time measurement should be implemented to provide an immediate feedback to design engineers to improve blast design over time with the goal of producing an optimal rock size distribution for downstream processes.

Measurement of Rock Fragmentation

Current Methods

Different methods have been developed for estimating rock size distributions. The most common methods are: visual observation, sieve analysis and image analysis. Visual observation involves inspecting the rock pile and subjectively assessing the quality of the blast. This subjective method can obviously lead to inaccurate and imprecise estimates of rock size distribution. Sieve analysis involves taking a sample of the rock pile being studied and passing it through a series of different sieve size trays. The rock size distribution is calculated by measuring the mass or volume of the rock material that remains on each tray. This method generates more consistent results; however, it is more expensive, time consuming and difficult to perform well as the sampled rock size distribution may often not be statistically representative of the whole rock pile. Image analysis methods have been developed with the rise of computer image processing and analysis tools. Conducting image analysis involves taking 2D photos, stereo images or 3D laser scans of the rock pile, and processing these images to determine particle sizes. Image analysis techniques enable practical, fast, and relatively accurate measurement of rock fragmentation. The most common image analysis technique applied in mines uses 2D fixed cameras located *(i)* at the base of a rock pile, *(ii)* on shovels and truck buckets, *(iii)* at crusher stations, or on conveyors in the processing plant to capture photos. However, the following limitations have been observed for these fixed, single-camera 2D image analysis techniques:

(i) Fixed single camera located at the base of a muck pile:
  - Scale objects must be placed on the rock pile.
  - Photos must be taken at a distance of less than 20 m from the rock pile. This can interrupt production and may place technicians at risk.
  - The shape of the muck pile can influence the accuracy of the image analysis.
  - Only a limited dataset can be collected from a fixed location.
  - Dust, fog, rain, snow and particulates can obstruct the image.
  - Lighting conditions can drastically impact the results of the image analysis.

(ii) Fixed single camera mounted on shovel booms or truck buckets:
  - This requires installing a camera with a clear view of the shovel bucket.
  - Equipment generates large amounts of vibration and shock during operation which can influence the

quality of images.

- Shielding is required to protect the camera from falling debris and direct sun light.
- Imaging the same material multiple times biases the results.

(iii) Fixed single camera installed in crusher stations:

- Detailed masking of images is required.
- Scale objects must be visible in image.
- Difficult to match material with source.
- Large amount of dust generation obstructs the image.

To overcome some of these limitations, 3D measurement techniques have been implemented that use LiDAR stations or stereo cameras to capture images. Using 3D measurements for rock fragmentation analysis eliminates the need for scale objects and reduces the error produced by the shape of the muck pile. However, the process of using LiDAR scans or stereo cameras for rock fragmentation measurement is still highly manual and the measurement results have low temporal and spatial resolution.

Measuring With UAVs

To overcome the limitations and to automate the data collection process, we use UAV technology to conduct a real-time rock fragmentation analysis. To demonstrate the feasibility and benefits of automated aerial rock fragmentation analysis, we designed a laboratory experiment, where we set up a muckpile with a known rock size distribution and conducted a UAV-based rock fragmentation analysis. The same muckpile was also photographed manually to compare both methods. The laboratory scale test was deemed to be necessary to optimize our UAV procedure before conducting any large-scale field experiments. Figure 1 illustrates the components and overall lab configuration used for the proposed automated rock fragmentation analysis. A detailed description of this setup is given in Bamford et al. (2016). Figure 2 is a photo taken of the UAV during flight with the raw and processed image for rock fragmentation measurement.

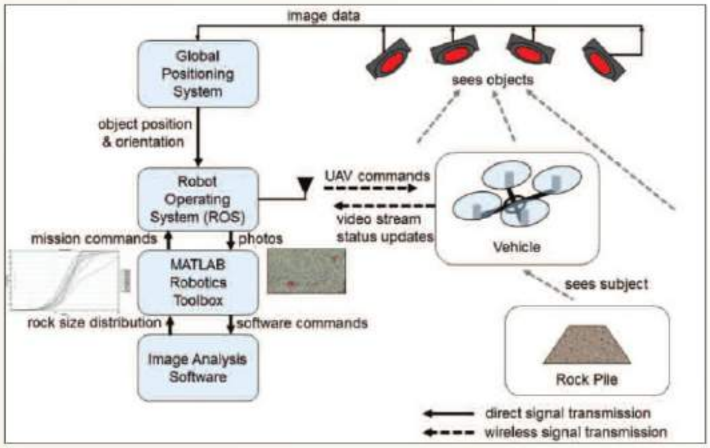

Figure 1: Block diagram of the lab configuration with arrows showing the typical information flow.

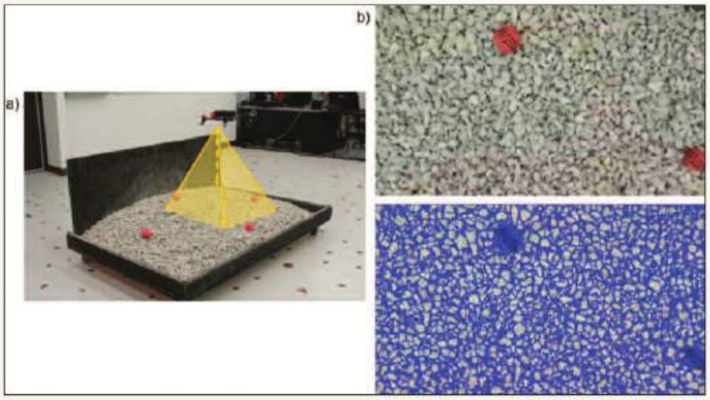

Figure 2: a) UAV (Parrot Bebop 2) in flight for automated image analysis. b) Raw and delineated photo captured by the UAV during automated image analysis.

Advantages of Rock Fragmentation Analysis Using UAVs

Throughout the development of the automated aerial fragmentation analysis system, we noticed a number of benefits. The main benefit is that the UAV system collects and analyzes images rapidly. This serves to reduce the cost to the operator and enables on-demand, real-time, high-resolution data collection. On top of this, the system provides results that are considerably more accurate. For these reasons, the UAV system is considered a valuable tool for real-time rock fragmentation measurement. Overall, the important benefits provided by the UAV system are:

- Collection of data does not interrupt the production process.
- UAV is capable of sampling regions of interest that are otherwise inaccessible by a human operator.
- Results are available in real-time allowing the real-time adjustment of the UAV's flight path to optimize the results of the fragmentation analysis.
- Real-time results also allow the immediate adjustment and optimization of blast designs.
- Surface sampling errors can be reduced with high-frequency measurements.
- Fragmentation analysis resolution can be easily adjusted to target different regions in the rock size distribution by flying closer or further away from the rock pile.
- Obstruction of the image by particulates can be controlled and avoided.
- Additional data collection, such as photogrammetry for volume calculations, can be performed simultaneously as part of the UAV mission.
- Sampling bias (resulting from taking the same image multiple times) can be controlled and extreme outliers can be filtered out in real-time.
- The system keeps operators out of harm's way in an active mining environment. A UAV is expendable; the human operator is not.

We compared the automated method of collecting rock size distribution information with conventional techniques using the designed lab configuration. In these experiments, UAV technology was shown to only take a fraction of the

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time (~20%) that a conventional method takes, to measure rock fragmentation within 6% of the conventional method's accuracy, where the conventional method deviates from the true distribution by up to 14% (Bamford et al., 2016). Figure 3 shows the two rock size distribution results that were measured using the conventional and automated methods for comparison.

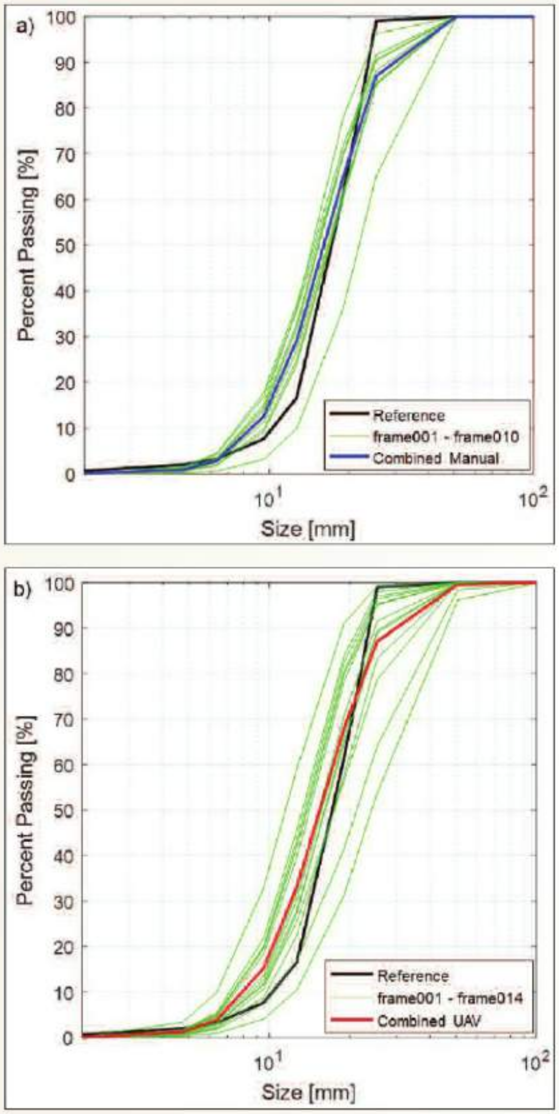

Figure 3: a) Manual, fixed-camera rock size distribution (blue),b) automated UAV rock size distribution (red) with the sieve analysis result in black as a reference. Results from the respective individual images are shown in green.

Future Development

Future work will focus on further optimizing the UAV capturing procedure and on implementing this system in an active mining environment to gain more insight into the system's prediction accuracy, the value added, and its ability to be incorporated into mine-to-mill process optimization. Ultimately, real-time acquisition of high temporal- and spatial-resolution data based on UAV technology will provide a broad range of opportunities for both improving blast design without interrupting the production process and reducing the cost of the human operator. The authors are also investigating other applications of UAV technology in mining such as automated rock discontinuity mapping for slope stability analysis, hyperspectral analysis of muck piles to control ore grade dilution, and real-time inspection and monitoring of surface excavations and earthworks. Interested industry representatives are encouraged to contact the authors for joint research opportunities.

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Link to Youtube video:
https://www.youtube.com/watch?v=TmC7qovR3ps

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