DEVELOPMENT OF A DRAGLINE IN-BUCKET BULK DENSITY MONITOR

Alex Bewley[1], Rajiv Shekhar[1], Ben Upcroft[2] and Paul Lever[1]

ABSTRACT

This paper details the implementation and trialling of a prototype in-bucket bulk density monitor on a production dragline. Bulk density information can provide feedback to mine planning and scheduling to improve blasting and consequently facilitating optimal bucket sizing. The bulk density measurement builds upon outcomes presented in the AMTC2009 paper titled 'Automatic In-Bucket Volume Estimation for Dragline Operations' and utilises payload information from a commercial dragline monitor. While the previous paper explains the algorithms and theoretical basis for the system design and scaled model testing this paper will focus on the full scale implementation and the challenges involved.

INTRODUCTION

A dragline is a large mining excavator used in open cut mining to move overburden above coal. These machines excavate overburden from a blasted bench using a large bucket suspended by hoist and drag ropes. Properties of the blasted overburden have an impact on the total energy spent on excavation, dragline performance and maintenance. Accurate estimates of the bulk density are beneficial to the open cut coal industry as they can provide:

1. a reliable assessment of dig and blast performance,
2. an improved bucket size selection to achieve consistent suspended load targets, and
3. decreased production downtime by reducing probability of bucket overloads and subsequent damage to the dragline.

This paper demonstrates a system for measuring the bulk density per payload in a dragline bucket during production. A prototype system was developed by CRCMining and trialled at Drayton Mine NSW. Particular interest in this paper is in the bulk density results and commercial prospects of this newly developed technology.

In-bucket bulk density is measured using the payload weight and the bucket fill volume. Bucket payload weight is commonly available through commercial dragline monitors while in-bucket volume measurement is the gap in the prior art that this and preceding papers fill (Bewley et al. 2009 and 2011).

[1] Department of Mechanical and Mining Engineering, The University of Queensland, CRCMining, QLD, Australia, 4067

[2] School of Engineering Systems, Queensland University of Technology, QLD, Australia, 4000

Literature Review

Accurate volume measurement in mining is increasingly becoming a topic of research and a metric for production. Duff used laser scanners to estimate the volume of the load in a haul truck tray as it passes through a weigh station (Duff 2000). In contrast to the ever-changing terrain experienced by a dragline, the environment surrounding the weigh station remains static. In more closely related work, Rowlands et al. used a stereo camera to quantify dragline bucket fill volume during the dig phase of a typical dragline cycle (Rowlands et al. 1997). Payload volumes were processed offline as computational resources for stereovision were not adequate in the late 1990s. Unfortunately, the accuracy of Rowland's results is unknown as no ground truth data was collected. Although real-time stereo processing is feasible at present, problems with lighting conditions (especially night operation) still require further study.

Volume estimation applications generally require the use of pose evaluation to match the observed points to a predetermined model of the object of interest. McInnes devised a set of formulae for measuring the out-of-plane motion of a dragline bucket by sensing the strain at two points on the boom (McInnes, 2009). This coupled with hoist and drag rope length information enables determination of the four degrees of freedom of the bucket (McInnes and Meehan, 2007). Ridley and Corke (2000) attempted to dynamically estimate the pose of a dragline bucket through the use of a kinematic model of the boom and bucket rigging.

The paper has the following structure, *In-Bucket Volume Sensing* section summarises the characteristics in the entire in-bucket bulk density system. In the *Results* section we demonstrate the accuracy of the system and long term bulk density monitoring. The paper concludes by listing research and commercialisation paths enabled through this research.

IN-BUCKET VOLUME SENSING

A typical dragline cycle consists of dig, swing, dump and return components. While swinging it releases the drag rope that moves a full bucket out to under the boom tip where the bucket rigging allows the material to be dumped. The bucket motion is controlled by the operator who adjusts hoist and drag rope velocities to move the bucket to the dump zone. Additionally swing accelerations cause the bucket to move in a normal direction to the boom plane.

A Sick LD-MRS laser mounted to a pan tilt unit (PTU) was chosen for imaging the bucket from an access platform located on the boom. The LD-MRS is an all weather laser that operates in rain and dusty conditions. The laser is set to *focused* mode where central angles have a finer resolution. This is beneficial in this application as this is typically where the bucket is located. During the swing, the payload surface of the loaded bucket is scanned by the laser with the resulting point cloud used to compute the payload volume. The laser is orientated to scan across the width of the bucket allowing the magnitude of the sway to be observed. The 2D bucket scans are collected consecutively to build a 3D profile of the bucket.

A previously modelled empty bucket profile is compared against the full bucket surface to measure the payload volume (Bewley et al. 2011).

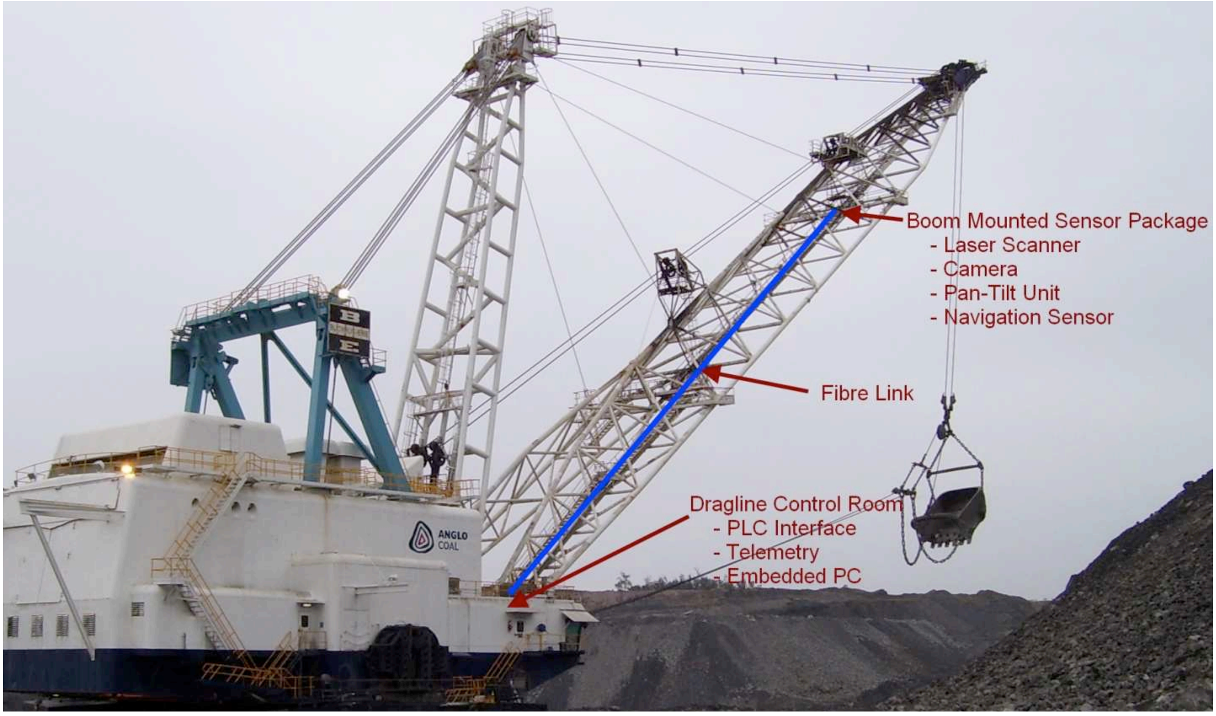

Figure 1 - System Setup showing boom mounted sensor package and control room equipment.

Figure 2 - Sensor Package Location, Left and centre: showing the installation to the first mounting location. Right: showing the second location on landing.

Site Installation

The boom mounted sensor package was trialled using two different mounting configurations. The first configuration positions the sensor package under the boom mounted directly to a horizontal boom cord. This centre position is optimal for visibility into the bucket including the inside walls of the bucket. The negative aspect of this mounting configuration is that it requires a 160 Tonne crane for access (Figure 2 left). A second mounting configuration was investigated that enables convenient access from the boom walkway and landing (Figure 2 right). This mounting location proved to have sufficient visibility of the bucket and allowed researchers and maintenance staff to inspect the sensor package on a frequent basis.

Empty Bucket Calibration

An accurate profile of an empty bucket is required to measure payload volume. This empty bucket profile is of critical importance as it is used both as a reference surface and bucket characteristics are used for determining the online bucket pose. Inaccuracies with the empty bucket profile will flow into the measurements of every bucket fill calculation. Three different methods are described for obtaining an empty bucket model.

Surveyed Bucket

Traditional surveying techniques can profile the bucket from the ground perspective with high accuracy. This is a proven technique and the required equipment is readily available on a mine site. Any non-standard fitted wear package or current wear status can be captured in this process.

Virtual Model

A computer aided design (CAD) model of the bucket provides a suitable empty bucket reference. As this is already in digital format noiseless capturing of the bucket geometry becomes trivial. Typical bucket motion is simulated to gather the scan points as would be expected from the boom mounted sensor in production. As the bucket is continuously wearing and undergoing maintenance the CAD model may become inconsistent with the actual bucket geometry. This is particularly common for older buckets with years of wear packages applied and worn from the bucket.

Self Calibration

The current wear state and 3D profile of the empty bucket can be captured using the boom-mounted scanner itself. This requires the sensor to be fitted with a tilting platform that allows the laser to scan the bucket during each downshift. By lifting the bucket off the ground the empty bucket profile becomes salient in the laser data. The entire scene under the boom is scanned and the bucket can be easily filtered.

RESULTS

On 24 June 2010, CRCMining carried out an in-bucket volume measurement trial at Anglo American Metallurgical Coal Drayton Mine, NSW. The purpose of this trial was to gauge the accuracy of the volumes calculated by the system in its normal operating mode against those measured with a high-resolution scan of the static dragline bucket.

Production Time Usage

The trial was carried out using 90 minutes of production time over three 30 minute blocks throughout the shift. During this time a total of 30 loaded buckets were stopped for static sweep scans before dumping.

Ground Truth Data Collection Method

Figure 3 illustrates the collection of ground truth data. After the bucket was pulled out of each dig the operator rested the bucket on the pad in a position directly under the laser position on the boom. The laser then takes four high-resolution sweeps of the bucket that produce 6000 to 8000 samples across the bucket surface. This is approximately ten times the number of samples collected dynamically as the bucket moves to the dump zone. Unfortunately, as the buckets were positioned on the ground for the static sweep scans, the payload system wasn't able to produce reliable payload weight values for the buckets collected throughout this trial.

Accuracy of Static Bucket Sweep

A static sweep of an empty bucket was carried out during the production time as a reference. Each individual sweep on the empty bucket were analysed with a median volume of -0.3 cubic metres or 0.57% of the Rated bucket capacity for the CQ93 bucket used at the time of the trial. This is considered to be an acceptable measurement error for the measurement of the ground truth data set.

Similarly, the loaded bucket sweep scans were individually analysed and the median sweep volume was used for each bucket. Any bucket that was observed to lose a significant amount of material between the static scans and dynamic scans was discarded. This material loss occasionally happened when the bucket was lifted off the pad just before the dynamic scan. Due to material falling out of the bucket before the dynamic scans took place, several buckets were ignored. Additionally, a few more buckets were disregarded as they experienced unusual rocking motion during dynamic scanning, which was not observed in data previously collected during normal production dig cycles. Lifting the bucket off the ground with slack in drag ropes inadvertently caused this motion.

Results of Analysed Bucket Volumes

The RMS error for the valid buckets is 3.74% with a negative mean error of -1.84% (Figure 4), which suggests that some of the error might be caused from small rocks which fell off the payload between static and dynamic scans.

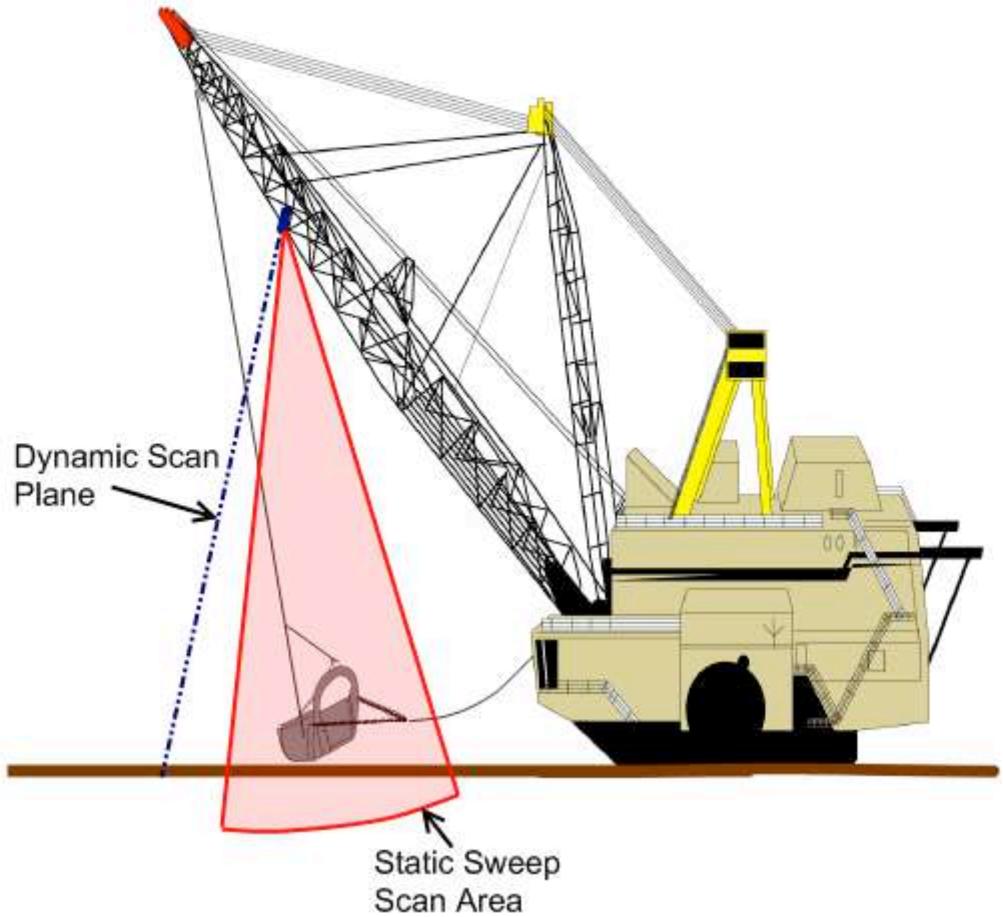

Figure 3 - Illustration of the ground truth data collection setup. Blue dotted line shows the single scan plane of the laser as part of the in-bucket bulk density system. The red shaded section shows the entire static sweep zone used as reference.

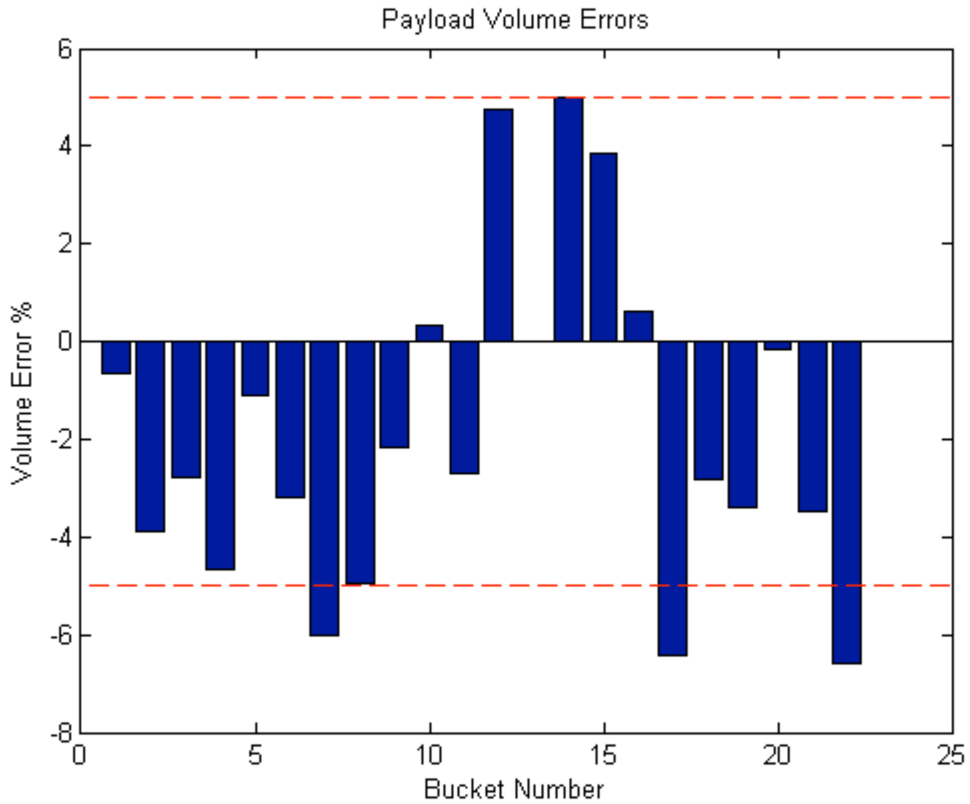

Figure 4 - Volume errors of valid production trial buckets. Only 3 buckets are outside the 5% reference.

The results show that our system can measure the in-bucket payload volume with a mean accuracy above 95%. This full scale data also reflects on the 95% performance achieved in the initial pilot studies performed using the 1:20 scale test facility at CRCMining (Bewley et al. 2009). When this volume information is combined with an accurate payload weight provided by a third party dragline monitor it is capable of measuring the in-bucket bulk density and could lead to improved bucket selection. The size of this sample set is relatively small for experimental purposes but due to the high cost of dragline production, 22 buckets is adequate.

Bulk Density Mapping

By using a GPS receiver and rope length information the dig location can be roughly estimated. This fusion of bulk density and spatial information allows bulk density to be mapped to difference areas of the blast and mine-site. As the dragline progresses across the blast, the dig location using rope lengths and GPS position is recorded with the in-bucket bulk density.

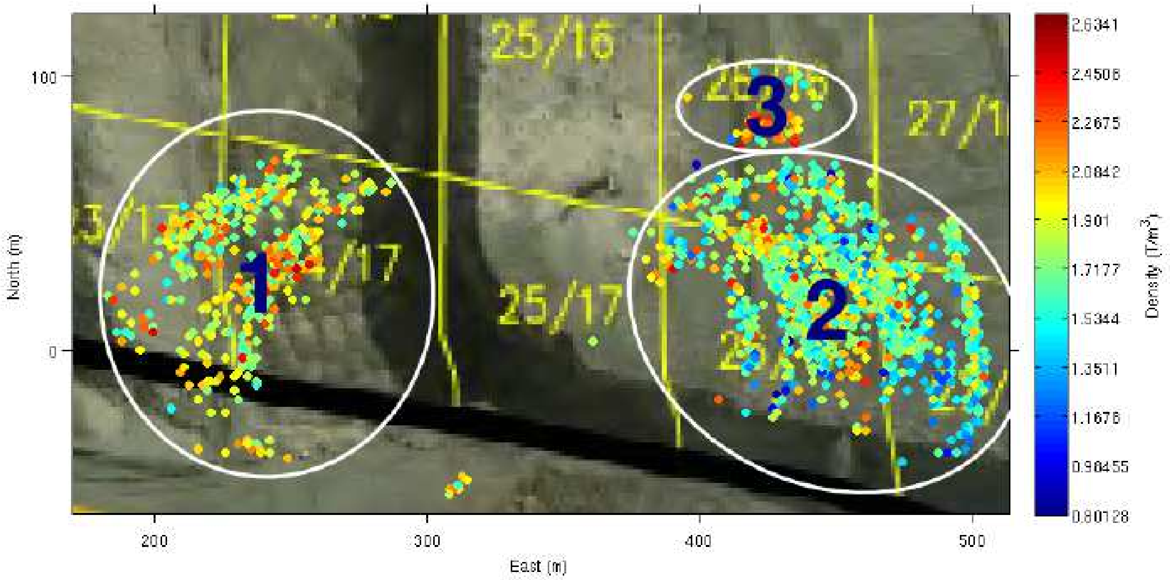

Figure 5 - 3 Days of buckets showing re-handle material (area 1) and blast (area 2). Divided by dig area and coloured by bulk density.

Figure 5 shows a scatter plot of all buckets dug over several days after the volume accuracy trial and overlaid on an aerial survey photograph. This data demonstrates a degree of correlation between the area from which material was dug and the measured bulk density of the material. This can be further illustrated by plotting an empirical distribution for the measured densities in each area (Figure 6).

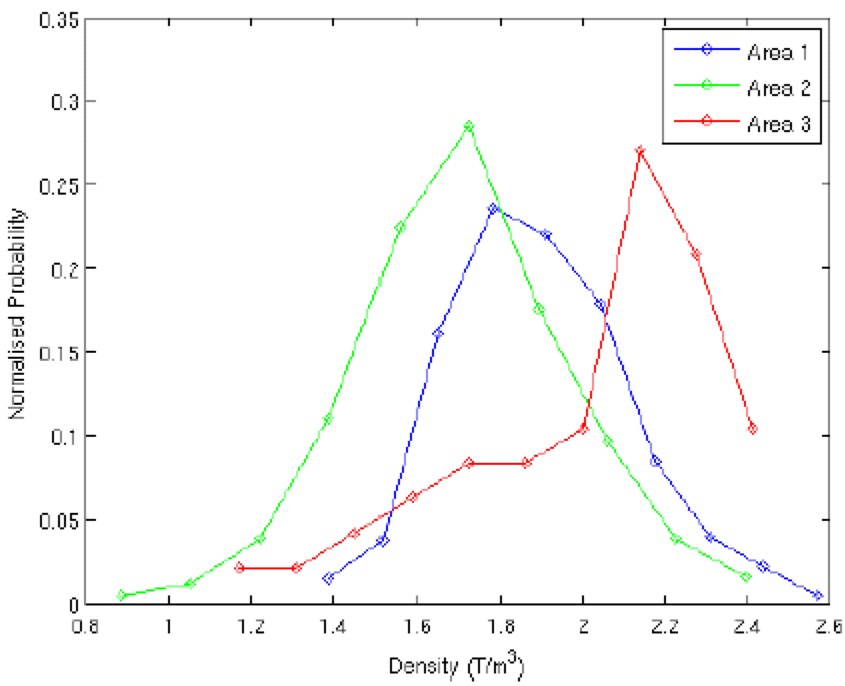

Figure 6 - Empirical density distribution for spatial areas identified in Figure 5

Consultation with site mining engineers provided some insight into the differences between the areas of Figure 5 and Figure 6. Specifically:

- The overburden dug in areas one and two were comprised of hard sandstone. Harder rock does not fracture very well, leading to dragline payloads with large particle sizes and therefore air gaps. These air gaps resulted in payloads with comparatively low bulk densities.
- The mean densities of areas one and two differed by about 10%. Although the rock type of the two areas is the same, material in area 1 was being re-handled. This additional handling created more fracturing, leading to smaller particle sizes and therefore higher bulk density.
- Initial loads dug in area three were comprised of a completely different, inter-burden (or parting) material. This material was much finer and softer than the sandstone of areas one and two, explaining the significantly higher mean bulk density, and potentially, the somewhat skewed distribution.

Although this data covers a relatively small section of the mine, the measured bulk density data appears to be in agreement with qualitative inferences that can be drawn from the nature of the payload material. This data also serves to demonstrate the utility of the bulk density mapping concept. A much larger dataset of 19980 digs was collected between 11th August and 28th September. Figure 7 and Figure 8 show the in-bucket bulk density pattern across the blast for this larger dataset.

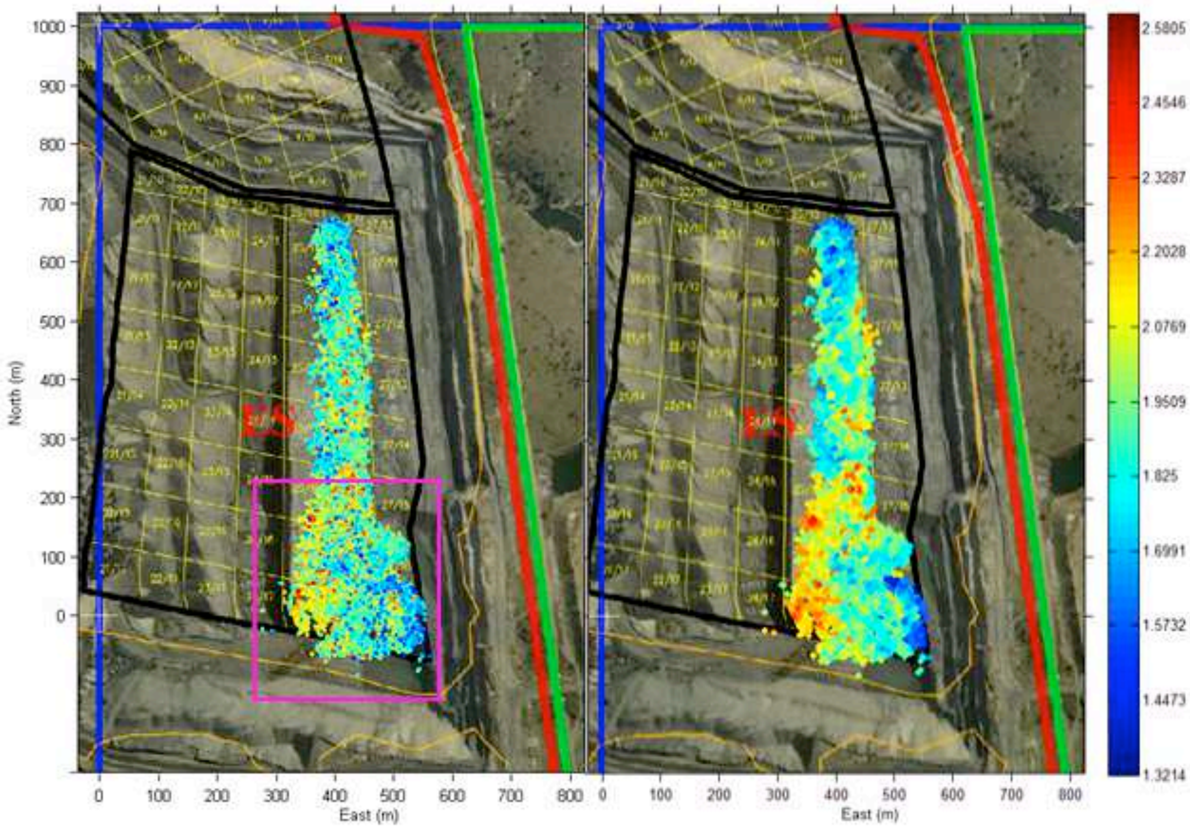

Figure 7 - Bulk density mapped across blast consisting of 19,980 digs collected between 11th August and 28th September 2010. The left image shows the raw coloured bulk density. The right shows the smoothed bulk density where each dig location bulk density is averaged using its neighbours. The rectangle section is zoomed in Figure 8

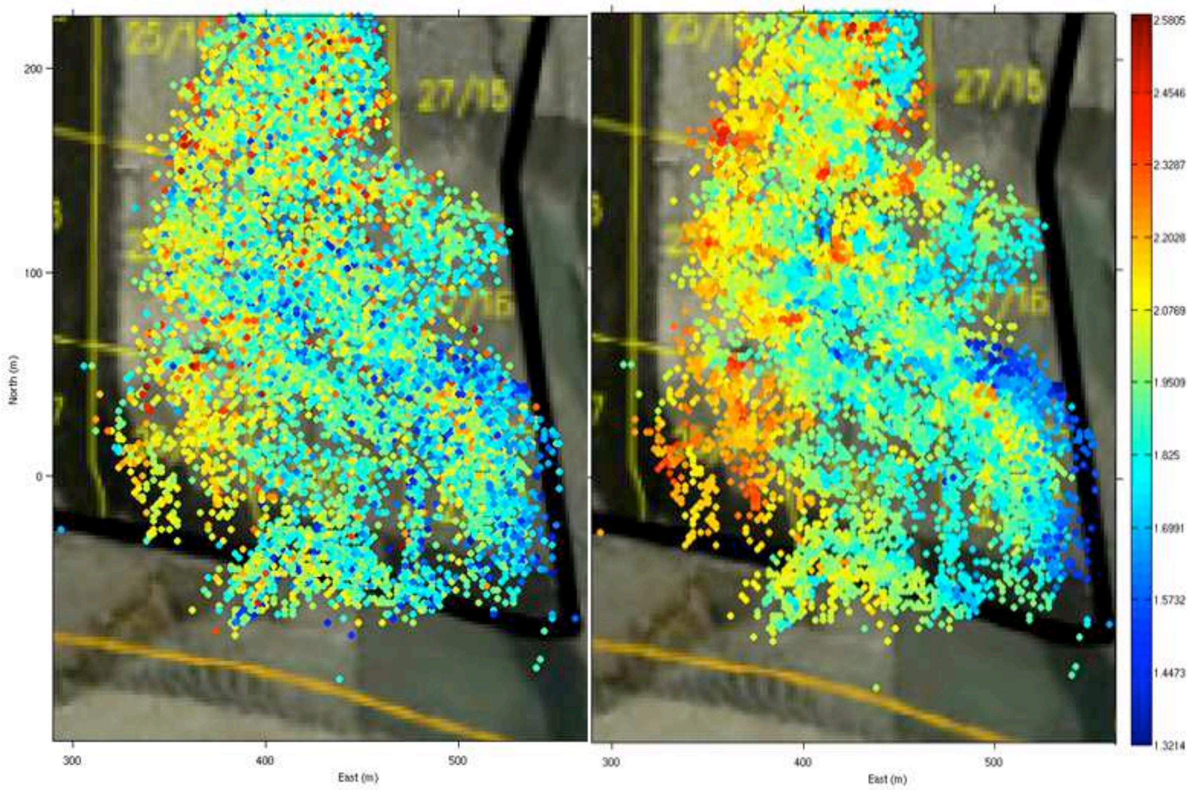

Figure 8 - Zoomed section of mapped bucket bulk densities. Left raw, right smoothed as in Figure 7

CONCLUSION

This paper has presented the results of a research prototype in-bucket bulk density monitor ready for commercialisation. The benefits of this research have already been realised by the host site after using the abovementioned data (Figure 7) in a bucket size selection study. Anglo American quantified the benefit of this system to increase dragline performance by five to ten percent. By using an optimised bucket size based on the average in-bucket bulk density experienced across each dragline pass could lead to an extra 100,000 tonnes of coal per annum per dragline.

It is planned that this technology shall soon be available commercially through MineWare. CRCMining have been working closely with MineWare to develop the first commercial version of this system. As this system uses mostly off-the-shelf hardware and custom software, transferring it to a commercial product is simplified.

This research provides a basic approach to measuring blasted bulk density for the purposes of improving blast performance. The volume of the material move can change as the bucket is filled. CRCMining are currently in the early stages of a project that attempts to measure the change in bulk density from in-place to in-bucket. This further research aims to provide an even better understanding of blast and operator performance than the work presented here.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given to the project by Graham Brooker, David Cusack, Nick Davies, Andrew Goodwin, Joel Kok, Sam Leonard, and Mick O'Ferrel. The research conducted in this paper was supported by the Cooperative Research Centre for

Mining (CRCMining) and Australian Coal Association Research Program (ACARP). Support and access to a production dragline provided by Anglo American Metallurgical Coal (Drayton) and staff is also acknowledged.

REFERENCES

Bewley, A, Upcroft, B, Lever, P and Leonard, S (2009) *Automatic In-Bucket Volume Estimation for Dragline Operations,* Proceedings of Australian Mining Technology Conference, pp 153-167.

Bewley, A, Shekhar, R, Leonard, S, Upcroft, B, and Lever, P (2011) *Real-Time Volume Estimation of a Dragline Payload,* IEEE International Conference on Robotics and Automation, pp 1571-1576.

Duff, E (2000) *Automated Volume Estimation of Haul-Truck Loads*, Proceedings of the Australian Conference on Robotics and Automation, pp 179-184.

McInnes, C H, (2009) *Modelling, Optimisation and Advance Duty Detection in a Mining Machine*, PhD Thesis submitted at The University of Queensland, Australia, pp. 47-49

McInnes, C H and Meehan, P A, (2007) *A four degree of freedom dynamic dragline model for predicting duty and optimising bucket trajectory*. CRC Mining Technology Conference. 2007. Perth, WA, Australia: The Australasian Institute of Mining and Metallurgy.

Ridley P, and Corke P, (2000), *Calculation of dragline bucket pose under gravity loading*. Mechanism and Machine Theory, Vol(35) pp 1431-1444

Rowlands, J, Phillips, M and O'Beirne, T, (1997) *Investigation into dragline Bucket Filling*, Final Report for ACARP, Project No. C3002