



Automatic Image Processing based Size Characterization of Green Pellets

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Abstract: The size of pellets has a significant effect on the performance of blast furnaces. Based on experience, the universally accepted size of pellets for efficient blast furnace operations is between 9 millimeters to 16 millimeters. But presence of smaller size pellets or fines lowers the blast furnace stack permeability, increases dust losses and may lower the maximum permissible blast temperature for smooth operation of the furnace. Pellets too big are also undesirable, particularly if its reducibility is low and is poor in strength, thus undergoing physical degradation during furnace operation. This paper relates to a non-contact method of measuring the size of green pellets being fed into the Blast furnace. A method is developed for the automatic size characterization of green pellets in the conveyor belts before the pellets are being indurated in a travelling grate furnace to confer the required physical and metallurgical properties. The method employs imaging and illumination devices installed in the conveyor belt in the pellet plant of Tata Steel and then, processing those images using imaging algorithms to obtain the size distribution. Apart from the size distribution of the green pellets, the system also identifies the pelletizing disc from which the green balls originated so as to effectively control the pelletizing process.

Keywords: image analysis, image processing, machine vision, metals

Introduction

Pellet plants agglomerate iron ore fines with other materials at high temperature, to create a product that can be used in a blast furnace. The final product, a pellet, is a small, round nodule of iron mixed with small amounts of other minerals. Pelletizing is a method used to create round objects from powders. Iron ore can be upgraded to higher iron ore content through beneficiation. This process generates iron ore filter cake which needs to be pelletized to be used in the steel making process. Also during the processing of high grade iron ores which don't need beneficiated, fines which are generated can be pelletized and used instead of being disposed of.

Iron Ore Pellets are formed from beneficiated or run of mine iron fines. The iron is usually ground to a very fine level and mixed with limestone or dolomite as a fluxing agent and bentonite or organic binders as a binding agent. If the ore is a Hematite ore, coke or anthracite coal

can be added to the mix to work as an internal fuel to help fire the pellets. This mixture is blended together in a mixer and fed to balling discs or drums to produce green pellets of size typically about 9-16mm. The green pellets are then fed to the induration machine. Both straight grates and grate kilns dry the pellets out in a drying section, then bring the pellets up to a temperature of about 800-900 °C in a preheat zone, then finish the induration process at roughly 1200-1350 °C. The pellets are then cooled to a suitable temperature for transporting to a load out facility. Both processes recycle the heat from the pellet back through the process to aid in energy efficiency and decrease fuel usage.

Both processes can be used to generate almost any type of desired pellet chemistry, from direct reduction pellets (DR pellets) to blast furnace pellets. By adjusting the amount of fluxing agent or limestone added, pellets can be made that are anywhere from acid (or non-fluxed) pellets to heavily fluxed pellets.

The size of pellets has a significant effect on the



performance of blast furnaces. Based on experience, the universally accepted size of pellets for efficient blast furnace operations is between 9 millimeters to 16 millimeters. But presence of smaller size pellets or fines lowers the blast furnace stack permeability, increases dust losses and may lower the maximum permissible blast temperature for smooth operation of the furnace. Pellets too big are also undesirable, particularly if its reducibility is low and is poor in strength, thus undergoing physical degradation during furnace operation. Particle size distribution of materials is one of the widely used tests to evaluate quality of materials and sieve analysis test has been used as the main method to determine particle size distribution of granular materials for many decades.

In recent times, image processing techniques have also been practiced in civil engineering field [1], especially in concrete engineering [2] - [4]. Images have mainly been analyzed to study shape characteristics of particles such as elongation and angularity etc. [5] - [6]. Image analyses have mainly been conducted using 2-D images. A few researchers have discussed shape characteristics of aggregates with 3-D images too [7] - [8]. In addition to shape characteristics, size characteristics of aggregates including particle size distribution with image analysis had also been discussed in the past [9] - [14]. Particle size distribution curve is produced with mass in sieve analysis test. In image analysis, gradation curve can be produced using volume (i.e., mass based), area or number of particles. In general, image analysis uses 2-D images.

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However, 2-D images cannot measure volume of particles directly. Banta et al. (2003) [11] studied particle gradation curves by 2-D images of 4.75-25mm size limestone and found that image analysis gave good results.

However, mass of individual particles were measured using a balance to compare gradation curves by the two methods. It was a time consuming process since mass of individual particles were measured. The method cannot be applied when there is large number of particles available. Kwan et al. (1999) [5] used 2-D images of coarse aggregates to study particle shape characteristics. In his research, volume of particles was determined from 2-D images with some assumptions. Mora et al. (1998) [10] also compared the gradation curves determined by image analysis and sieve analysis test using 2-D images. He also determined mass of particles from 2-D images with some assumptions. The results showed that the grain size determined by image analysis overestimated the grain size determined by sieve analysis test. A size correction factor was assigned to grain size to obtain the same gradation curve as that by sieve analysis test. Therefore, it is not clear whether the assumptions made in evaluating mass affected the difference or image analysis techniques themselves had some effects on the gradation curves.

Fernlund (1998) [9] studied particle form on sieve analysis with 32-64mm size railroad aggregates using 2-D images. He also compared gradation curves determined by mass and number of particles in sieve analysis. The results showed that rain size determined by number of particles underestimated that by mass. A few other researchers also found inconsistencies between gradation curves determined by volume (i.e., mass based) and number of particles [13].

Since gradation curves determined by mass and number of particles were found to be different in sieve analysis test, it is not worthwhile to use number of particles to determine gradation curves in image analysis. Fernlund (2005c) [12] measured three axes of particles of 10-50mm size granite while manually changing positions of particles. 2-D images of same particles were taken twice to measure dimensions of the three axes. The gradation curve determined by image analysis was compared with that obtained by Danish Box. The results showed that 2-D images, when particles placed on a stable location, gave good results. However, it was a time consuming process due to the fact that location of particles had to be manually changed twice to obtain images to measure dimensions of the three axes.

Kumara et al. (2011) [14] evaluated gradation curves of gravel using image analysis. He used area of particles to evaluate gradation curves. However, it should be noted that in sieve analysis, gradation curves is evaluated using mass of particles. Therefore, to compare gradation curves



by the two methods, gradation curve should be evaluated using mass of particles in image analysis.

As mentioned in literature, usually, volume of particles has been determined using 2-D images with some assumptions or using time-consuming process where measuring mass of individual particles. It was also seen that the gradation curves determined by image analysis were different from the gradation curve determined by sieve analysis. In this paper, a method is proposed to automatically measure the particle size distributions using Image processing along with the design of an image acquisition system.

Current Operational Practice at Tata Steel

Current operational practice in Tata Steel involves sieve analysis in the lab once or twice every 8 hours for analyzing the size distribution of the pellets. In this practice, the particles of various sizes are segregated using sieves and then by using their weight ratios, a distribution is provided assuming that the process follows a normal distribution. Based on these weight ratios, mean and standard deviation values are provided to the operators for understanding and if possible, control of the process. But there is a time lag between the sample collections and no real-time measurement, there is no means for the operator to control the process.

Proposed Approach

Based on the central limit theorem, the size distribution of the green balls in the conveyor belt can be assumed to follow normal distribution. This assumption is crucial for this approach since, an imaging based approach basically covers only the top layer of the green pellets in the conveyor belt. Hence, it is assumed that the top layer is representative of the complete cross section of the green pellets and also, that the size characterization of green pellets can be represented using a normal distribution curve with mean and standard deviation values.

Figure 1 provides the schematic diagram of the proposed approach. Pellet plants in general, are highly dust prone and hence, the luminosity of the illumination provided should be very high to negate the effects of dust. Camera and lens selection is also crucial taking into account the distance of the object from the conveyor belt and also, taking into account the width of the conveyor.

Hardware architecture of the proposed approach

The proposed approach comprises of an image acquisition system for efficient capturing of images, an image processing algorithm for deriving the results

necessary from the images, a database server for data storage and a webserver for publishing the results. Figure 2 provides the hardware configuration of the proposed approach.

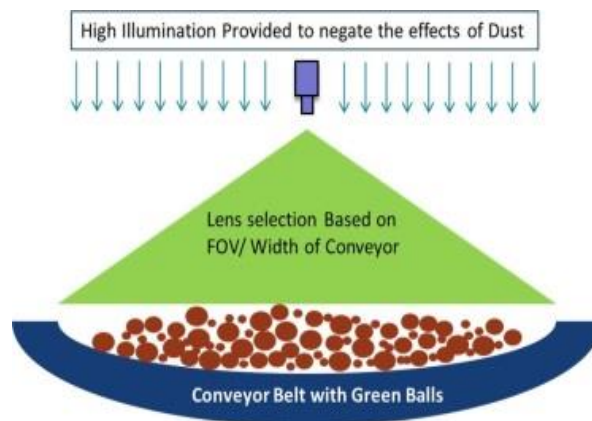


Figure 1. Schematic diagram of the proposed approach.

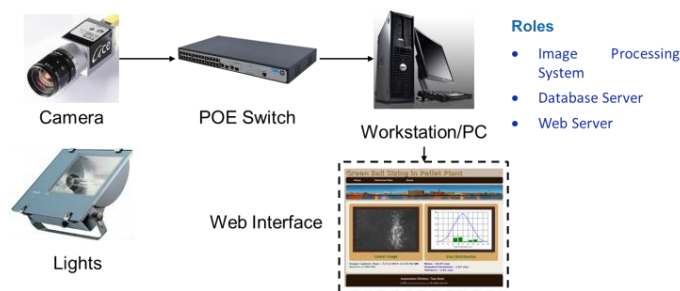


Figure 2. Hardware configuration of the proposed approach.

Algorithm

The images obtained by the image acquisition system are processed to obtain the size distribution of the particles under the basic assumption that all the particles of the system are circular in geometry and hence, can be characterized by the diameter. This is done by segregating and separating the various particles using canny edge detection algorithm. Once the particles are separated, the images are processed using a series of morphological filters (Bridging, Dilation, Top hat filters, Image subtraction etc.) in an iterative manner in such a way that no two particles are characterized more than once. After this step, based on the previous assumption that the particles have a circular geometry, the diameter of each of these particles is calculated using blob detection algorithms in the form of number of pixels as shown in figure 3.

Finally, the various particle diameters obtained by the algorithm is accumulated and provided in the form of a normal distribution curve with the mean and standard deviation of the sizes. This provides a visual aid to the operator of the blast furnace in the form of numbers, so as to control the blast furnace in a more efficient manner.

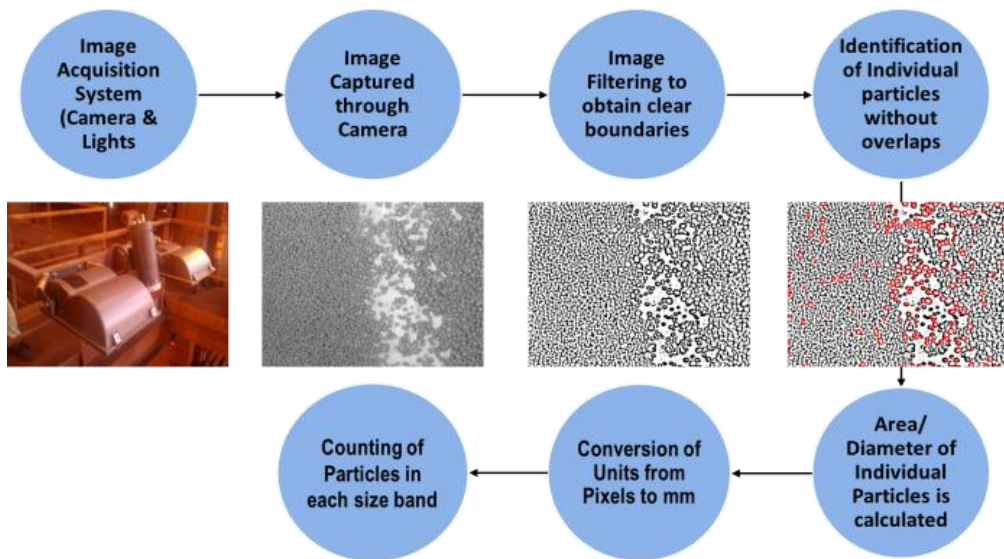


Figure 3. Schematic diagram of the algorithm.

Differential Greyscale Blob detection of green pellets

There are two main classes of grey-scale blob detectors, one based on local extremum in the intensity landscape called watershed detection and the other on derivative expressions called differential detectors. The main problem with the watershed detection is the sensitivity to inherent noise and over segmented results. To overcome these problems differential blob detector has been used. This can be explained mathematically as follows:

Let us consider the Gaussian $g(x, y; \sigma)$:

$$g(x, y; \sigma) = \left(\frac{1}{2\pi\sigma^2}\right) e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (1)$$

where σ is the standard deviation. We define scale-space representation $L(x, y; t)$ of the image $f(x, y)$ by

$$L(x, y; t) = f(x, y) * g(x, y; \sigma) \quad (2)$$

where $*$ is the convolution operator and $t = \sigma^2$ is the variance.

Most common differential blob detectors use the Laplacian operator ∇^2 applied to the scale-space representation of an image:

$$\nabla^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} \quad (3)$$

$$\nabla^2 L = \nabla^2 (f * g) = (\nabla^2 g) * f \quad (4)$$

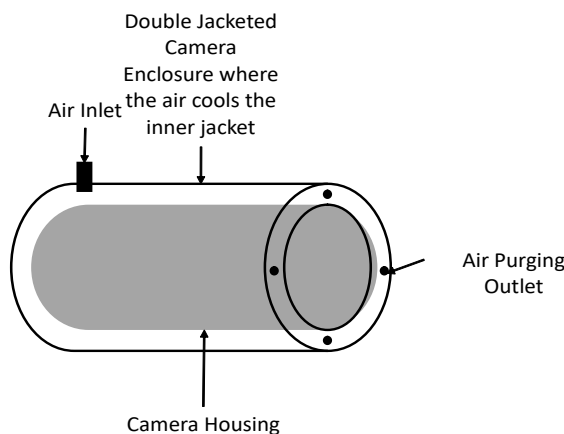
Applying (3) to (4) yields Laplacian of the Gaussian (LoG):

$$\nabla^2 g = -1/\pi\sigma^4 \left[1 - \frac{x^2 + y^2}{2\sigma^2}\right] e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (5)$$

The Gaussian has been used to smooth an image and to attenuate noise. The Laplacian highlights regions of rapid intensity change and is therefore often used for edge detection. As scale t of LoG increases, edge-like points converge to the unique point of local extrema at some scale. This intuition motivates using LoG filter in blob detection of green pellets.

Implementation and Improvements

As mentioned previously, pellet plants are usually very prone to dust, thereby capable of degrading the quality of images from the camera. Hence, the design of the enclosure of the camera (As shown in Figure 4) and the lighting assembly has a compressed air purging unit with a pressure of about 5 bar, thereby creating a positive pressure and not allow the dust to affect the system. Also the enclosures are so designed that the compressed air also cools the camera and lighting assembly while also purging the faces of the camera and lighting assemblies



for better viewing and illumination capabilities



respectively.

Figure 4. Camera Enclosure Assembly.

The illumination and image acquisition system was deployed above the conveyor belt as shown in Figure 5.



Figure 5. Illumination and image acquisition system.

Installation included using a power over Ethernet camera, since providing AC power supplies at the location is considered a safety hazard.

Since, the Single camera system deployed only covered nearly 80% of the conveyor belt; an improvement was made with the implementation of two camera system along with extra illumination as shown in Figure 6. This improves the coverage of the conveyor belt to 100 percent. Moreover, different heaps of pellets are formed based on the pelletizing discs they are made from. Hence, we have implemented a disc wise online size measurement system.

This can be used for closed loop control of the individual discs thereby, increasing the impact of the system.



Figure 6. Implementation of the two camera system.

Results

The system provides outputs in the web that can be accessed across the company. Figure 7 shows the output of the single camera system.

It shows the last image capture time along with the mean, variance and standard deviation of the measured pellets. Based on these values, a normal distribution curve is plotted for ease of understanding of the operators. The following are the salient features of the web based

reporting system where the results are published:

- ✓ Web-based system accessible anywhere in in the company for the operators and managers
- ✓ Home page provides the live image and the size distribution
- ✓ Auto Refresh Feature to update on new data.
- ✓ The home page provides the status of the system.
- ✓ Historical data has two parts – minute wise data for 8 hours of that day and obtain day wise data for a maximum of 6 days.
- ✓ The About page provides the Literature survey.

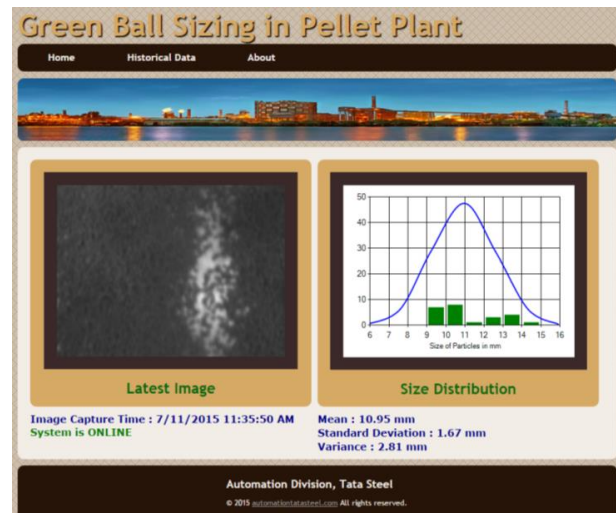


Figure 7. Web based output of the system.

Figure 8 provides the heap wise data of the conveyor belt. Basically there are 10 pelletizing discs and each heap is formed by the output of two discs thereby forming 5 heaps. The mean and Standard deviation of each of the heaps are provided to the operator so that corrective action can be taken on those defective discs only, thereby providing an effective means of control.

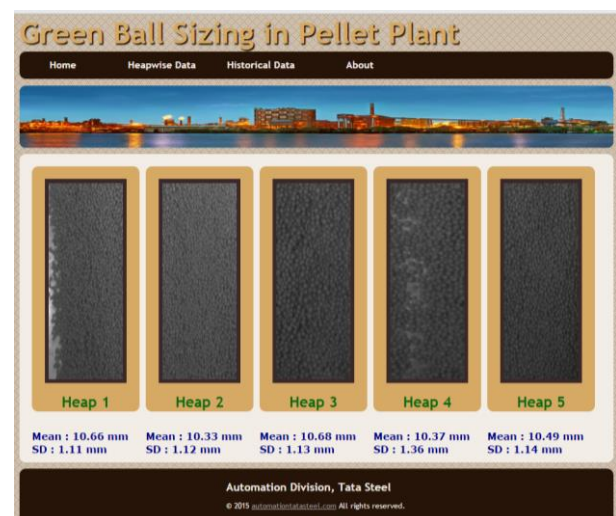


Figure 8. Heap wise output of the system.

Validation

Validating the data captured by the imaging based system is crucial for the plant managers to adopt the Imaging based system. For the purpose of validation, Data from the sieve analysis was compared to the imaging system. For this purpose, the data was gathered for a period of 7 days through both the sieve analysis and the imaging system and the plot is as shown in Figure 9.

Based on the data above which shows the Mean and Median of the data captured by the Imaging based system and the purple lines show the time the data is collected for the sieving analysis.

The following are the observations from the plot above:

- ✓ The trend is being followed between lab and camera data.
- ✓ The difference between the camera and lab data has a difference of 1 mm nearly at all times.
- ✓ It can be inferred that since the trend of the data is being followed by the camera system and also that the data is available real time, it can be used for developing control mechanisms.

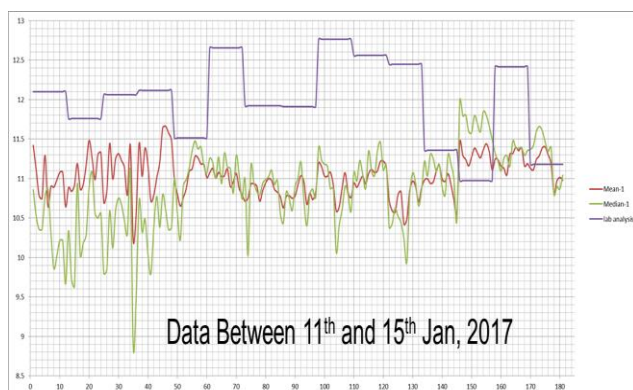


Figure 9. Data was gathered for a period of 7 days through both the sieve analysis and the imaging system.

Conclusion

Based on the data validation provided above, currently the operators are using this system to gauge the size distribution and make changes to the operating parameters to maintain the size distribution. This convinced the operators to use the imaging system independently for controlling the operations of the green pelletizing discs.

In the proposed system, a method is developed for the automatic size characterization of Green Pellets in the conveyor belts of steel plants using image processing techniques. This system also shows the cumulative values of the distribution over different periods of time, so that the operator is able to assess the average distribution and tune the parameters of the pelletizing discs to improve the

physical properties of the pellets. This application of image processing in the Pellet plants proves to be very robust in terms of being independent, thereby providing greater control of the Pellet plants.

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