Particuology 12 (2014) 80–89

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic

# Particle shape characterisation and its application to discrete element modelling

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ARTICLE INFO

*Article history:*
Received 29 December 2012
Received in revised form 19 February 2013
Accepted 28 February 2013

*Keywords:*
Particle shapes
Particle morphology
Image segmentation
Discrete element modelling

ABSTRACT

Increasing importance has been placed on particle shape implementation within discrete element modelling (DEM) in order to more accurately reflect the non-spherical behaviour of the bulk material being handled. As computational resources grow, complex particle shapes are increasingly being modelled as the associated simulation times become more realistic to provide timely solutions. The objective of this research is to assess particle shape descriptors through a digital image segmentation technique, and to further implement particle shape parameters into generation of corresponding irregular shaped DEM particles. Separated and lumped particle images were analysed and reconstructed through the development of two distinct methodologies. Subsequently, various particle shape descriptors were obtained using combinations of image segmentation algorithms, including mathematical morphology processing, thresholding, edge detection, region growing, region splitting and region merging. DEM particles were subsequently created using particle shape results obtained above. Shape parameters of DEM particles were then examined and validated against the real particle shape parameters.



## 1. Introduction

Discrete element modelling programmes have either utilised the clumping behaviour of spheres or directly modelled irregular shaped particles as super-quadratic "blocks", faceted polyhedrons, briquettes and cylinders to enable non-round shape capability. Although three-dimensional feature of the particle is the ultimate aim, proper identification of two-dimensional particle characteristics can be used to achieve adequate design of three-dimensional aspects of the DEM particles. Typically, two-dimensional particle shape descriptors are the perimeter length, the surface area, the smallest circumscribed and the largest inscribed circles, and Feret diameters/box type methods which are used to describe length, breadth and thickness. Additional particle shape descriptors can be based on roundness and circularity, elongation (aspect ratio), convexity, solidity and polygonality. To date, there are some online systems available for continuously collecting 2D particle shape information, for example, the programme WipFrag collects 2D data images on a conveyor belt (Maerz, Palangio, & Franklin, 1996). However, those systems are not capable of producing reproducible and representative results for particle shapes (Maerz, 2001).

More recently, the increase in computational speed has progressively allowed a complex image segmentation method (Gonzalez, Woods, & Eddins, 2004) to perform particle shape characterisation at a reasonable frequency from optimal digital imageries captured. Such a method is based on similarity of neighbouring pixels having a similar value in an area (e.g. greyscale, red, green and blue), subsequently this area is specified as one region in the segmented image. Algorithms using this feature are usually mathematical morphology processing, thresholding, edge detection, region growing, region splitting and region merging.

The pioneer work of adopting a digital image processing technique to obtain particle shape properties was conducted by Lin, Yen, and Miller (1993) who utilised morphology processing and thresholding techniques on onyx stone particle images obtained from a rapidly moving conveyor belt. Kemeny, Devgan, Hagaman, and Wu (1993) attempted to apply a delineated image segmentation method on a well-mixed rock particle image. Additionally, researchers have also used similar image processing techniques during blasting processes to evaluate the particle shatter/breakage effectiveness (e.g. Schleifer & Tessier, 2002). Whereas, the advancement of the image segmentation on the overlapping particles imagery was achieved by Wang (1998, 1999,

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http://dx.doi.org/10.1016/j.partic.2013.02.014

**Nomenclature**

$A_{merged,conv}$ convex hull area of the merged region
$A_{merged}$ real area of the merged region
$C_1$ convex merging criteria 1
$C_2$ convex merging criteria 2
$C_3$ solidity threshold in the convex merging criteria
$m$ rows of the image matrix
$n$ columns of the image matrix
regclr sum of the standard colour deviations in a region
regdev colour deviations of a region
$regdev_{thresh}$ colour deviations threshold of a region

2008) who developed a polygon approximation method to be combined with the edge detection technique. However, the results compared poorly to visual inspections.

This research aims to develop image segmentation programmes for attaining particle shape characteristics from separated or overlapping particle digital images. The initial work focussed on particle shape characterisation using an image segmentation programme on separated particle imagery. Subsequently, overlapping or lumped particle imagery was interrogated using the developed particle image methods to identify single particle formations. When single particle identification was completed, individual particle shape descriptors were subsequently calculated. Finally, DEM particles were generated and examined based on particle shape descriptors and methods defined in this research.

## 2. Digital image sampling system

The image sampling system used for the research was shown schematically in Fig. 1. The material selected in this research was iron ore. Separated particles/lumps were initially positioned on a white background with a shaded scale (100 mm by 10 mm). Such a scale provided a reference measure on particle shape parameters for post image segmentation analyses. Only ambient lighting was used during the image capturing as this generally proved sufficient for the analysis. Flash or other photographic/video specific lighting was trialled, however was found to reduce image quality as surface details were lost and/or contrast of the particle edges was reduced. A number of digital images were taken approximately 300 mm above the background with different particle orientations.

## 3. Separated particle imagery

To extract particle shape descriptors from the separated particle imagery, mathematical morphology (Serra & Soille, 1994) and the thresholding (Otsu, 1975) of the image segmentation techniques are often used. Mathematical morphology is a critical tool in performing filtering, smoothing and pruning to prepare the image for a better thresholding result. Additionally, mathematical morphology is also useful in the representation and description of region shapes (boundaries, skeletons, and convex hulls). The image processing methodology for the separated particles is defined via the flowchart shown in Fig. 2.

Two fundamental morphological operations were involved in the morphological process of a digital image, dilation and erosion, which use a structuring element. Dilation is an operation that

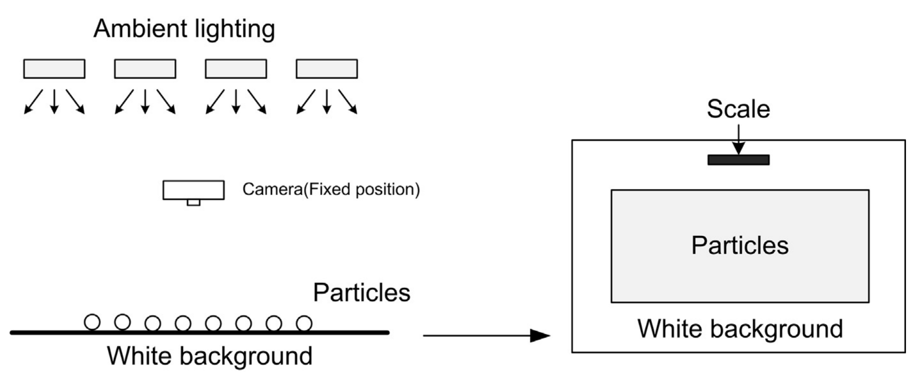


**Fig. 1.** Schematic diagram of the image sampling system.

**Table 1**
Shape parameters of particles in the separated particle imagery.

| Particle number | Surface area ($mm^2$) | Perimeter (mm) | Polygonality | Aspect ratio | Circularity | Largest inscribed circle diameter (mm) | Smallest circumscribed circle diameter (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 572.70 | 594.66 | 6 | 1.74 | 0.76 | 22.10 | 37.84 |
| 2 | 947.58 | 778.61 | 6 | 1.56 | 0.80 | 30.60 | 47.61 |
| 3 | 329.10 | 461.89 | 6 | 1.83 | 0.75 | 17.47 | 31.09 |
| 4 | 470.40 | 540.23 | 5 | 1.46 | 0.79 | 20.44 | 31.96 |
| 5 | 598.19 | 630.01 | 6 | 1.30 | 0.78 | 23.01 | 37.80 |
| 6 | 1070.19 | 840.83 | 5 | 1.61 | 0.76 | 29.83 | 50.82 |
| 7 | 407.82 | 551.00 | 6 | 2.29 | 0.65 | 16.83 | 39.41 |
| 8 | 249.19 | 400.13 | 6 | 1.69 | 0.75 | 15.95 | 28.03 |
| 9 | 400.37 | 522.66 | 6 | 1.30 | 0.78 | 19.98 | 32.72 |
| 10 | 603.36 | 631.30 | 5 | 1.19 | 0.79 | 23.55 | 37.51 |
| 11 | 585.90 | 591.97 | 6 | 1.37 | 0.81 | 25.32 | 37.79 |
| 12 | 448.25 | 506.29 | 6 | 1.17 | 0.87 | 23.35 | 30.49 |
| 13 | 311.04 | 470.53 | 5 | 1.99 | 0.70 | 15.91 | 31.75 |
| 14 | 320.93 | 477.29 | 6 | 1.87 | 0.71 | 16.80 | 32.65 |
| Mean | 459.33 | 545.62 | 6 | 1.58 | 0.77 | 21.27 | 35.12 |