Sensitivity of particle size and shape parameters with respect to digitization

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ABSTRACT

The growing success of image analysis based instruments for particle characterization demonstrates the importance of size and shape analysis in operations involving particulate materials. ISO norms for particle sizing using image analysis are being elaborated to clarify nomenclature and measurement principles. But despite this, there is still a lack of understanding of how the digital representation of a particle affects different size and shape parameters. It is the purpose of this paper to explore the magnitude of estimation errors of a series of size and shape parameters from different digital image representations of a single particle. These images are simulated from grey level images of black particles presenting a Gaussian transition towards their white background. Particles themselves are generated from analytical functions sampled by digital grids with variable densities, positions and orientations. Results of inscribed disk, elongation, circularity, roughness, roundness, etc. are plotted as a function of grid density (magnification) with error bars corresponding to the scattering of results for variable thresholds, grid translations and rotations As a conclusion, confidence intervals are given for parameters as a function of magnification and the most sensitive and robust methods of shape analysis are put forward.

KEYWORDS: Shape analysis; Robustness; Digital representation

INTRODUCTION

The literature on size and shape analysis of fine particles is extremely extensive and reflects an incredible diversity of approaches. The reason for diversity is due to the fact that particles are dealt with in many different disciplines (food, pharmaceutics, minerals, biology, astronomy, …) and their description has been tried with every new method appearing in the literature (Fourier transforms; fractals; wavelets; mathematical morphology; etc.).

With the development and widespread use of commercial instrumentation the need for an ISO norm has become evident. Nowadays, a series of simple size and shape parameters are described and designated with a standard terminology (ISO 13322-1 Particle size analysis - Image analysis methods - Part 1: Static image analysis methods; ISO 9276-6: Descriptive and quantitative representation of particle shape and morphology).

A question that has been overlooked in many papers is how image digitization impacts on the accuracy of size and shape estimates. This question will be addressed in this paper.

QUALITY ATTRIBUTES OF SHAPE DESCRIPTORS

From our daily experience, it is evident that a shape descriptor of a particle should be clearly independent of its size. But, in practice, some authors have clearly suggested dimensional parameters as shape indices and other authors have underestimated the impact of particle magnification on the robustness of their proposed parameter. It is Exner [1] who most clearly stated the elementary criteria a shape descriptor has to obey: independency; additivity; relevance; accessibility; sensitivity and robustness. In this work, we will more specifically focus on the questions of independency, sensitivity and robustness.

Independency

Most modern researchers agree that shape information cannot be captured within a single parameter. Hence, different levels (scales) of shape have to be defined and each level must be quantified in an independent manner. Pirard [2] suggested parameters ranging from global to local named Elongation; Roughness; Roundness and Angularity. Despite this, most parameters found in the literature and in the ISO norm contain an underestimated intrinsic correlation to the aspect ratio that affects performance in discriminant analysis of different products. Fig. 1 shows the simple relationship between axial ratio (a/b) and circularity for an ellipse.

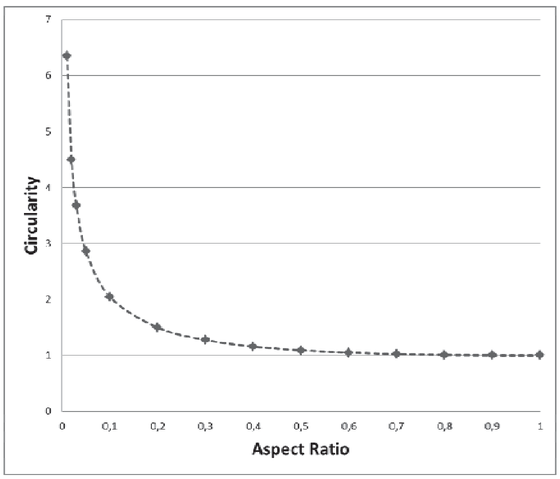

Figure 1: Intrinsic correlation between classical shape factors for a series of ellipses.

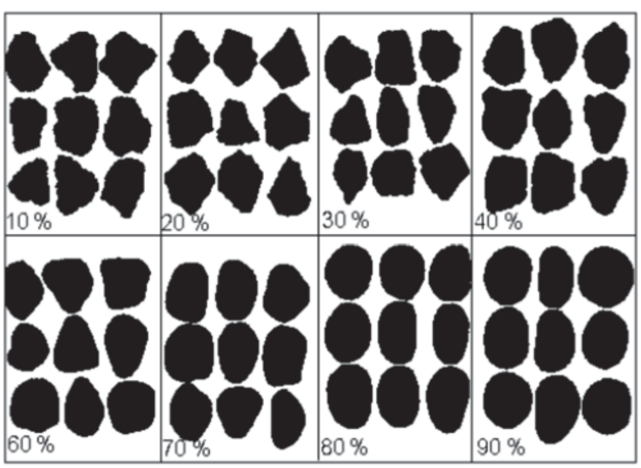

Figure 2: A popular morphoscopical chart used to evaluate shape roundness in geology and related sciences [3].

Sensitivity

Sensitivity relates to the capability of a shape descriptor to capture slight but significant differences between particles under similar digitization conditions. A good example is given by the automation of Krumbein's morphoscopical chart (Fig. 2). Pirard and Gregoire [4] showed how this can be best automated using an "equivalent roundness" parameter derived from the set of all morphological openings. Fig. 3 clearly indicates that circularity as defined in the ISO norm does not have the same ability to discriminate among different classes of particles. One should however bear in mind that Krumbein's particles are drawings and cannot be considered as an ideal reference material for validation.

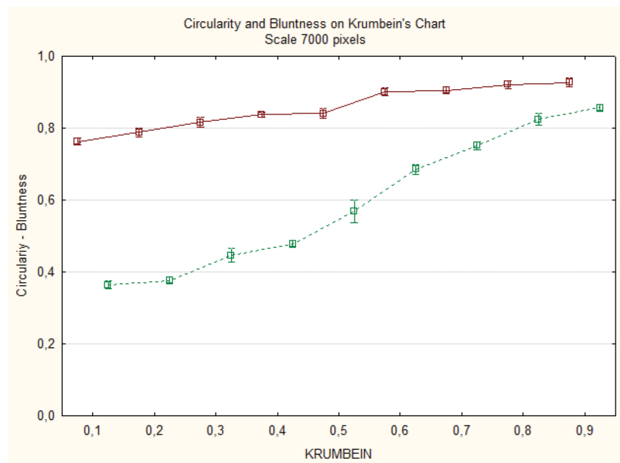

Figure 3: Standard error of mean intervals obtained from the equivalent roundness (bluntness) and circularity measures on particles from Krumbein's classes 1 (10%) to 9 (90%).

Robustness

In accordance with Serra [5], the essential point is not to know whether a set in R^2 is digitizable or not, but whether the pair set-transformation (or set-measure) is digitizable. Many size and shape measures are claimed to be independent of translation and rotation in a Euclidean space, but very few has been done to test how they behave on a discrete grid under variable magnification, translation and rotation conditions. In the next paragraph we will show some additional results to graphics published earlier [6], with special reference to ISO recommended parameters.

MATERIAL & METHODS

Sub-pixel simulation of elliptical shapes

Simple drawing of discs and ellipses on a discrete grid is not acceptable for simulating variable magnification, translation and rotation conditions. Therefore, a special algorithm was developed aiming at properly digitizing an ellipse with a given aspect ratio (a: long axis; b: small axis), positioned with sub-pixel accuracy in the image plane and oriented along a given direction θ with respect to the horizontal axis of the digital grid.

In practice, ellipses are drawn from their analytical equations in x, y space. Every pixel of the final grid is subsampled into a 16 x 16 grid and the number of sub-pixels falling outside the ellipse are converted into a grey level on a 8 bit scale. Hence, a value of 100 means that 39.06% (100/256) of the ellipse covers this pixel (Fig. 4).

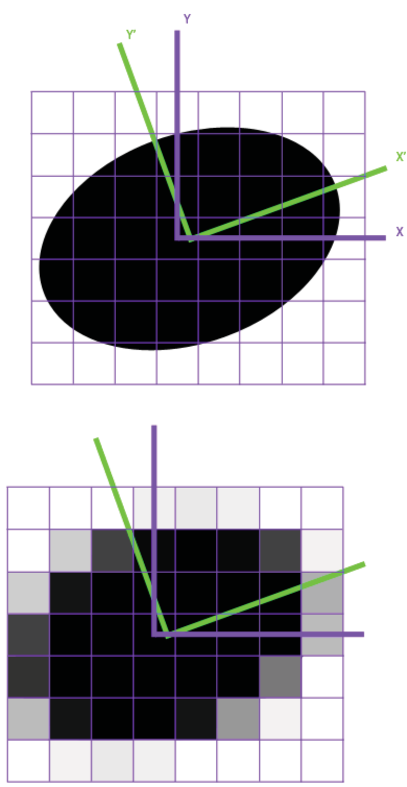

Figure 4: Drawing of an ellipse on a discrete grid and its grey level representation based on the density of spatial covering.

The simulated ellipse can then be thresholded at different levels to mimic optical smearing or modifications induced by an operator.

Krumbein's test particles

Another series of test images has been built by using a high resolution representation of Krumbein's chart (10 000 pixels/grain) and subsampling it progressively down to less than 100 pixels/grain as shown in Fig. 5.

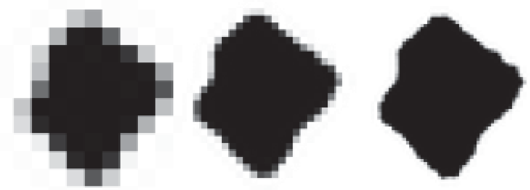

Figure 5: Representation of a grain from Krumbein's 90% class at different densities ranging from 70 to 1750 and 7 000 pixels.

RESULTS

A lot of experimental data have been obtained linking ISO shape and size parameters to variations in pixel density (nb of pixels per particle), thresholding, rotation and eccentricity with respect to the grid. As an example, Fig. 6 illustrates how the estimation of the diameter of a circle evolves with pixel density for a given eccentricity.

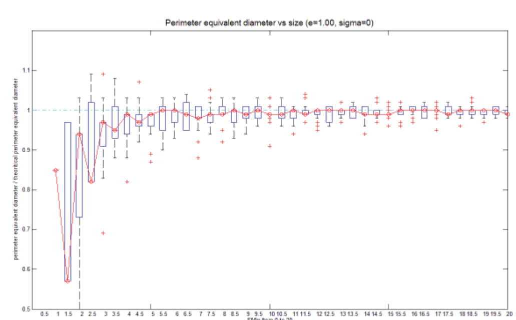

Figure 6: Evolution of the diameter estimated from Crofton's perimeter divided by the theoretical diameter as a function of pixel density (expressed in number of pixels from 0 to 20).

Another series of results have been obtained by gathering ISO and non-ISO shape and size measurements on particles from Krumbein's chart at different resolutions.

Fig. 7 illustrates how the equivalent roundness (bluntness) resists to the degradation of particle representation from 7000 down to 400 pixels per particle. This means, in practice, that bluntness still measures the correct trend at lower pixel densities, but that any comparison of particles with strictly the same shape but different sizes will result in considering smaller particles to be more rounded. However, if the aim is to compare two products of similar size ranges taken under similar imaging conditions, the parameter will still be able to properly discriminate particles from different classes.

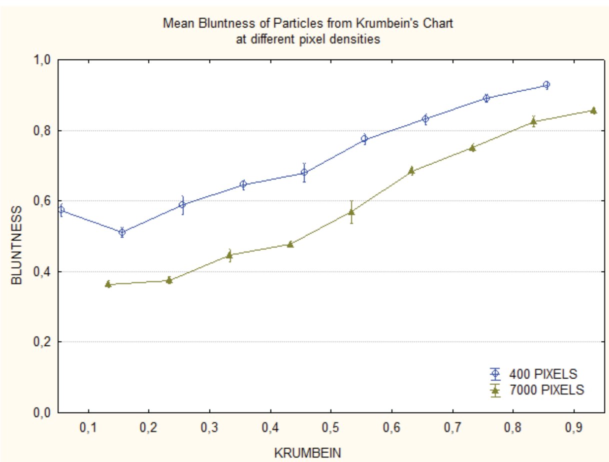

Figure 7: Standard error of mean on all particles from Krumbein's chart as obtained at two different pixel densities (400 and 7 000).

CONCLUSIONS

Simulations such as the ones illustrated in this paper generate a huge amount of data that have to be analyzed and converted into standard procedures. The systematic understanding of how size and shape measures are affected by digitization is of paramount importance to be able to derive meaningful conclusions when comparing datasets obtained from different image analysis instruments or using different algorithms.

A large number of works in particle analysis conclude that roundness increases in the lower size ranges. Though this can indeed be observed in practice and has a physically sound explanation, it is the author's opinion that most of these studies have been affected by poor digitization of the smallest size fraction.

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