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Interactive comment on "Identifying sediment transport mechanisms from grain size-shape distributions" *by* Johannes Albert van Hateren et al.

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Dear anonymous referee,

Thank you for your positive review and valuable comments and suggestions. Below we have made a list of your comments (in quotation marks) and our replies.

Comment 1) "A more detailed description of the technique is suggested (Some suggested points: Why are these methods better than previous sizing techniques? What are the advantages and drawbacks compared to other imaging approaches? The repeated pumping of the sample causes data redundancy [one particle will appear on

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more than one captured frames]. Is it a problem, or not?).”

1A) “Why are these methods better than previous sizing techniques?”

Many methods for measuring grain size have been/are employed, the most prevalent being sieving, settling and laser diffraction. The first advantage over these methods is obvious: in addition to size analysis, image analysis allows measurement of grain shape, the traditional methods do not. The second advantage is less obvious: the varying shape of natural sediment particles causes deviations in the size measurements obtained by sieving and laser diffraction: A sieve mesh actually measures the intermediate diameter of a particle and relatively large yet elongate particles can pass the mesh. With settling measurements, one has to make an assumption of the particle’s shape (and density) to convert settling velocity to grain size. In laser diffraction, the assumption is made that all particles are spherical. Since natural sediments are generally not spherical, this causes errors in the obtained grain size distribution. Grain size as obtained by image analysis is more robust in this sense: the (2D) shape of the particle is known, and therefore one can choose any definition of ‘particle size’. For example, the largest diameter (2D), smallest diameter (2D) or ‘average diameter’. We feel the latter is the most robust. For this reason, we used a diameter based on the surface area of the particle (D2d), as described in the manuscript. The third advantage of image analysis over traditional sizing techniques is that information is obtained on the size of each single grain passing the camera rather than just the grain size distribution of the entire sample. This means 1) that single grains with a certain size can be extracted from the data for specific research questions. For example, one may want to know the largest grain per sample, 2) that single very large grains are detected (in our experience this is not the case with laser granulometry), 3) that grain size distributions can be made by percentage of the total volume of all grains per size class, but also by percentage of total diameter or percentage of total number of particles, 4) that there are more options for statistical analysis of the sediment samples (which are as of yet not used).

There is however also a major drawback to the new technique: due to the pixel size of approximately 5 μm (or 2 μm with a different set-up which allows measurement of finer-grained particles but limits the maximum measurable grain size to 400 μm due to the 500 μm cuvette width), a reliable measurement of particle shape is not possible for anything finer than medium silt (Shang et al., 2018). Aeolian silt transport processes as fingerprinted by dynamic image analysis of the grain size and shape characteristics of Chinese loess and Red Clay deposits. Sedimentary geology, 375, 36-48). This is a financial, and not a technical limitation: the boundary could be lowered substantially with higher-resolution cameras.

1B "What are the advantages and drawbacks compared to other imaging approaches?".

The main advantage of dynamic image analysis (where particles pass a camera suspended in air or water) compared to the more classic static image analysis (where particles are photographed, for example under a microscope) lies in its statistical robustness and low measuring time: many particles can be measured in relatively little time (5 minutes for a typical number of particles of 150 thousand for sand (this manuscript) or 5 minutes for $\sim$ a million particles for silts (Shang et al., 2018)). The large number of particles ensures that the size-shape distributions are statistically robust.

There are additional differences with the static methods: If the sample consists of unconsolidated sediment spread out on a flat surface, the orientation of the particles is known: particles lying on a surface have their smallest axis oriented vertically, and therefore their largest and intermediate axis show up on the image. This is both an advantage and disadvantage over our method: it is favourable that the orientation is known, but any inferences about the volume of the particles will always be underestimations of the actual volume.

Non-automated measurements using a microscope enable the computation of shape variables that are difficult to automate, such as surface texture of the grains or Power's roundness. However, such measurements are user-dependent, very time consuming and will comprise only a limited number of measured grains leading to less robust results.

1C) “The repeated pumping of the sample causes data redundancy [one particle will appear on more than one captured frames]. Is it a problem, or not?”

The most often used method for measuring grain size is laser diffraction. In most of the laser diffraction set-ups, the sample is repeatedly pumped through the cuvette as well. Therefore, this “problem” is universal in grain size measurements. In our view, however, it is not a problem but rather something that adds to the strength of the measurement. Because the flow in the large cuvette is quasi-turbulent, the particles will pass at different angles each time. The total measurement therefore becomes to some extent a 3D average of the various 2D shapes that one obtains by looking at a particle at different orientations. A size-shape distribution therefore becomes more robust then had the sediments passed the camera only once.

Comment 2) “The description and the presented flow diagram ensure the reproducibility of the introduced measurement and data processing approach for experts of the field, but researchers without deeper knowledge on image analysis-based grain size and shape characterization may have trouble to understand the key steps of the method.”

We assume that this comment deals mainly with chapter 2.2 (dynamic image analysis). We might enhance apprehensibility of the chapter by adding a short description of the flow diagram:

[[In the first step of the script some limitations and conditions are set (execution of the script will be stopped at a certain number of particles/ images and the size of a pixel in the image is given as well as the grain size below which a particle will be excluded from the measurement. Subsequently, the script iterates over each video, over each frame in the video and over each particle found in the frames. For each particle, the length of its outer edge (perimeter) is computed, as well as its area and the length of its convex hull (a polygon drawn around the particle without taking into account the concave areas). These basic parameters are stored for each particle. Particle size, volume, aspect ratio, convexity and Cox circularity are subsequently computed from these basic parameters.]]

In our opinion, chapter 2.3 (construction and unmixing of size-shape distributions) and chapter 2.4 (artificial datasets for testing and validation of the method) go into sufficient detail to explain the method to non-experts.

Comment 3) “The applied self-written Matlab script (with imfill, regionprops and convhull functions) is using the raw images of the acquired frames not processed data of the Sympatec Qicpic’s software, allowing for a more detailed and freely customizable data handling. Are there any differences among the results of your own calculations (by using ‘regionprops’) and ones by the device software?”

Besides flexibility and customisability, there are two reasons for applying a self-written script:

3.1) The Qicpic’s software (our version at least) does not allow filling of blank spaces in particles. These blank spaces occur because some minerals, such as quartz, are transparent, causing them to appear donut-shaped in the images. Due to our quartz-rich samples, we were not able to use any of the built-in functions for computing area-based shape parameters. Matlab, on the other hand, has built-in functions to perform the task of filling blank spaces in objects. At the moment, however, we use the perimeter to determine the 2D surface area of the particles and therefore blank spaces are less of a problem.

3.2) The Qicpic’s software (and many of Matlab’s built-in functions such as regionprops(’ConvexHull’)) consider pixels to have an area (a pixel is a little square). In our method, we base computations on the pixel’s centre location.

Comment 4) “The presented size-shape distributions are equivalent to volume-weighted scatter plots of size and different shape parameters of individual particles. (It is a relatively well known approach of image analysis-based granulometric characterization, actually, a default data visualization mode in the software of Malvern Morphologi automated static image analyser device)."

We were not aware that grain size-shape distributions are a well-known approach. The size-shape distributions or volume-weighted scatter plots of size and different shape parameters can indeed be found in Malvern's documentation: https://www.cif.iastate.edu/sites/default/files/uploads/Other_Inst/ Particle%20Size/Particle%20Characterization%20Guide.pdf. Furthermore, we found one application in powder metallurgy: Takashi Itoh & Yoshimoto Wanibe (1991) Particle Shape Distribution and Particle Size–Shape Dispersion Diagram, Powder Metallurgy, 34:2, 126-134, DOI: 10.1179/pom.1991.34.2.126. However, we found no applications of a similar method in sedimentology. Thus, grain size-shape distributions are not new, but their application to the study of sediments is new. More importantly, the combination with end-member modelling is also new. We therefore propose to change "In this study we outline a new method for determination of sediment transport processes involving 1) the integration of grain size and shape data into size-shape distributions and 2) end-member modelling on these distributions." (Introduction, page 3, lines 8-9) to: [[In this study we outline a new method for determination of sediment transport processes involving 1) the integration of grain size and shape data into size-shape distributions (e.g. Itoh and Wanibe, 1991) and 2) end-member modelling on these distributions]].

Comment 5) "Last columns of Table 2 are not visible in the manuscript."

Thank you for noting this error. Part of the last column is indeed not visible in the manuscript. This will be changed in the revision.

Comment 6) "The overall structure of the paper is good, however, figure from the Appendix A could be moved into the main text."

Appendix A will be moved into the main text of the revision.

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References

Shang, Y., Kaakinen, A., Beets, C. J., & Prins, M. A. (2018). Aeolian silt transport processes as fingerprinted by dynamic image analysis of the grain size and shape characteristics of Chinese loess and Red Clay deposits. Sedimentary geology, 375, 36-48

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