Automated High-Resolution Static Imaging Analysis of Low-mass Suspended Sand

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Abstract

The standard for measuring the physical parameters of discrete sand size particles between 62.5 and 2000 microns has been by sieve analysis. Both dry sieve and wet sieve methods perform exceptionally well when there is sufficient mass to overcome the uncertainties inherent in these methods. Weighing uncertainties, lodged sample particles or dislodging of particles within sieves from prior samples, and sample handling while conducting the sieve analysis are some influences for size distribution precision. These uncertainties can overpower the essential accuracy with low mass samples, giving variable results. As stated by Harold P. Guy, (Laboratory Theory and Methods for Sediment Analysis, 1969) the minimum mass of sand for an accurate sieve analysis is about 0.02 grams. More mass is required if the sample contains particles larger than 1.0 millimeters (mm). Many suspended-sediment samples received by USGS Sediment Laboratories fall below this limit. For the past three years, approximately 8% of suspended sediment samples processed by the 8 USGS Sediment Labs were samples below the recommended weight limit for analysis reliability.

New techniques, either direct or indirect have been long sought out and tested that would be comparable to sieving to produce physical dimensions, with imaging being a promising alternative method.

Introduction

Imaging is a direct method alternative for measuring physical dimensions of discrete particles. When particle size distribution data are approximately between 62.5μm to 2000μm, and the sample mass falls below the limit of 0.02 grams, imaging analysis is a viable particle-size analytical method. When the particles are generally separated, and edges are pronounced, two-dimensional static particle imaging can provide the precision and accuracy comparable to a sieve analysis. Static imaging analysis for sand, dry versus suspended in a liquid, has the benefit of having particles on a single plane, so depth of field (DOF) becomes less of an issue. There is no liquid medium to degrade the particle images, no random particle orientation, and better particle separation.

There are four properties of imaging analysis that are significant for providing accurate results: maximum contrast, particle dispersion/separation, edge gradient that clearly defines discontinuities in the grayscale signal, and sufficient pixels to clearly identify the smallest targeted particles. With the combination of these, the uncertainties will decrease, and results will be reliable.

To discretely measure each particle within a sample and when the field of view is limited to a few millimeters, it can be a tedious task to perform manually and can become susceptible to errors. This paper demonstrates an automated system in which samples can be setup and have the analysis be completed automatically.

Inherently, most particles will orient themselves on the plane surface having their “a” (Maximum) and “b” (intermediate) axes perpendicular to the lens. This allows the image processing to measure the “b” axis which is the axis that determines the finest sieve aperture that will pass or retain the particle. Open-source imaging functions are used to transform the images to produce accurate particle measurement by defining discrete particles and enhancing their edges. Once an image has been simplified by morphological processing, measurements are computed to give a quantitative analysis of the particles that includes size and shape. The data from the individual particles are aggregated to produce a whole sample particle-size distribution. Size distribution by imaging is based on size population within size bins. Each detectable particle is discretely counted.

Materials and method

Equipment

A machine vision camera coupled with an appropriate lens is an essential part of imaging analysis. The lens magnification must provide adequate pixels to identify the smallest particle of interest. The setup for this test uses an Imaging Source monochrome camera, ½ CCD Sony sensor with a 0.5x magnification lens. The field-of-view is 7.68mm x 5.76mm for a 1280 x 960-pixel image, for a minimum target size of 62.5 microns. Approximate working distance equals 18.5 cm. A short-passband wavelength (near the blue side of the visible spectrum) LED backlight is used to create a sharper particle edge and to improve contrast.

A computer numeric control (CNC) table with a carriage using 3 stepper motors, designed to move in a linear path, incrementally pauses equally at each Field of View (FOV) width to capture an image over the entire acrylic imaging plate. The CNC program essentially divides the imaging plate into a matrix of ‘i’ rows and ‘j’ columns. After each move the camera is automatically triggered and image is stored. A single sample may have several hundred images once completed. Once stored, sample images are ready to be processed through the analyzing software.

Particle dispersion across the imaging plate is vital in preventing connecting or overlapping particles that can be interpreted as a single large particle. There are few dispersal methods that are suitable. For this test a micro-splitter was used (Figure 1). Sand size particles are released through the splitter and onto the acrylic imaging plate. The white side panels are to prevent sand grains bouncing off the plate.

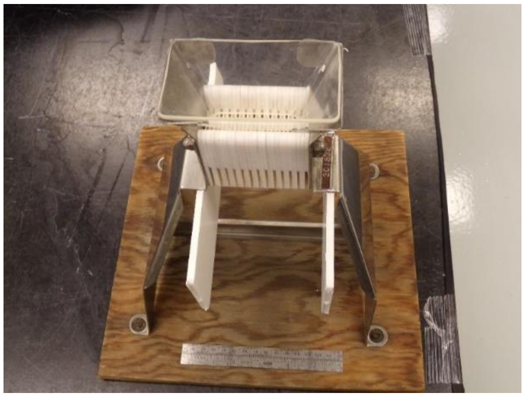

Figure 1. Micro-splitter, 2mm vane spacing. Particles pass through the splitter and drop two inches onto the imaging plate. The white panels below the vanes prevent particles from bouncing away from the designated area.

The dispersal of 1.2 grams, 250-500μm sand, is well distributed and ideal for imaging (Figure 2).

Figure 2. Sand size particles after being dispersed. Achieving a comprehensive particle dispersion can prevent misrepresentation of a Particle Size Distribution. Any particles overlapping may be interpreted by the software as a large single particle, biasing the distribution. (note: these particles were dispersed over a white surface and with a standard SLR camera just to show the pattern of particles after dispersion).

Testing

For this test, 20 images were used, and a total of 78 particles were measured. The material used was pre-sieved dry sands between 250-500μm. One of the images displayed (Figure 4), shows five particles, two of which are touching. The software recognized the joining particles as two separate grains. Image processing was conducted using Matrox Inspector 8.0, a commercial image-processing program. The images were binarized using a threshold grayscale value of 128 grayscale units. The software computed the measured properties of the blobs detected in the binarized images.

As a performance check, the software marks the perimeter and the feret diameter for the maximum and intermediate axis (Figure 4 & 5).

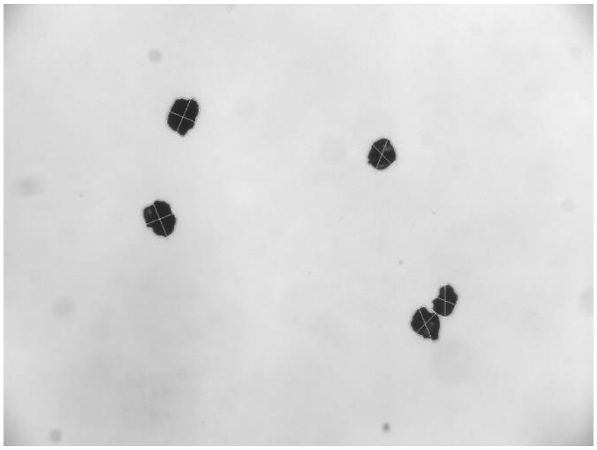

Figure 4. The perimeter and the A and B axis measured by the software are automatically highlighted. Two particles in the lower right were connected. The imaging software did a very good job measuring the particles separately.

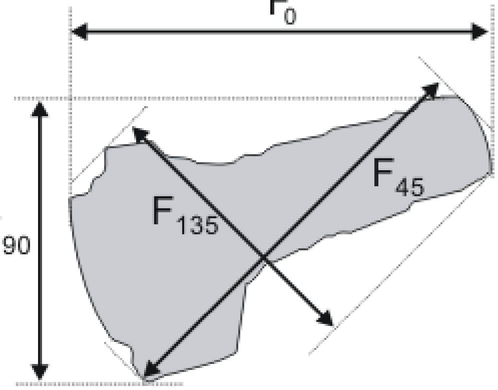

Figure 5. Explanation of the software algorithm for computing feret diameter: "Diameters are determined by checking the Feret diameter of the blob at a specified number of angles. Increasing the number of angles tested increases the accuracy of the results, but also increases the amount of processing time. The maximum Feret diameter is not very sensitive to the number of angles, and 8 angles usually gives an accurate result" (Matrox Electronic Systems Ltd, 2005).

The particle-size distribution for the entire population of 78 particles was computed in a Microsoft Excel spreadsheet. The particles were assigned to a quarter-phi size bin based on the minimum ferret diameter determined by the software. The particle volume of each particle was computed as the volume of a sphere that had a radius equal to the radius of a circle that had the same area as the particle. The volumes of the particles in each size bin were summed to produce the volume in each size class. The volumetric particle-size distribution was then computed based on the estimated volume in each class. As long as there is no systematic difference in the density of the particles with their size, the particle-size distribution produced this way is equivalent to the mass-based particle-size distribution.

Results

The test sample was comprised mainly of particles within 250-500μm. A few particles in the image were found outside of this range, but that was expected from the dry sieve sample used for this test. Generally, the results demonstrate that the imaging analysis did relatively well

(Table 1). Ninety-one percent of the particles in the sample were within the range of 250 - 500µm as shown (Table 1).

Table 1. Imaging data is combined into 1/4phi size bins. Last column shows the cumulative percent finer

Bin Min (retained on)	Bin Max (passing)	Bin Name	Particle count	Est volume in class (um3)	Vol. Percent in bin	Cutoff size (um)	Cumulative percent finer
0	63	<63um	1	0.0002	0.0%	63	0.0%
63	75	63-75um	1	0.0002	0.0%	75	0.0%
75	90	75-90um	1	0.0005	0.0%	90	0.0%
90	106	90-106um	0	0.0000	0.0%	106	0.0%
106	125	106-125um	0	0.0000	0.0%	125	0.0%
125	150	125-150um	0	0.0000	0.0%	150	0.0%
150	180	150-180um	0	0.0000	0.0%	180	0.0%
180	212	180-212um	0	0.0000	0.0%	212	0.0%
212	250	212-250um	2	0.0272	1.0%	250	1.1%
250	300	250-300um	10	0.2070	7.8%	300	8.8%
300	355	300-355um	35	0.8660	32.4%	355	41.2%
355	425	355-425um	18	0.7590	28.4%	425	69.7%
425	500	425-500um	8	0.5906	22.1%	500	91.8%
500	600	500-600um	1	0.0972	3.6%	600	95.4%
600	710	600-710um	1	0.1220	4.6%	710	100.0%
710	850	710-850um	0	0.0000	0.0%	850	100.0%
850	1000	850-1000um	0	0.0000	0.0%	1000	100.0%

Conclusion

The test sample demonstrated in this paper did not incorporate organic particles, though one image did show a single blob that was visually confirmed as organic material. The software excluded this organic particle. Organic material usually has its own visual signature: elongated, unusual angles (contour smoothness), features like narrow or thin (compactness), and semi-transparent. Special imaging processes can filter these out from the images prior to the calculations. In some cases, particles may be connected to organic materials. In those situations, it is very difficult for the imaging algorithm to interpret. This can greatly bias the results. As the imaging software development progresses, it will be able to mark particles having some level of uncertainty and give the analyst the opportunity to visually inspect the point in question and decide whether to eliminate the particle from the results.

Initial results show imaging analysis can be a viable method for producing a particle size distribution for light mass sediment samples. Both dry and wet sieving methods have fundamental uncertainties. This doesn't exclude imaging analysis. What is important is to know what those uncertainties are. Four important factors can skew the results in static imaging: orientation of the particles (both “a” & “b” axis must be viewable); overlapping or connecting particles; clearly defining particle edges; and the presence of organic material, each will contribute to the sample result uncertainties.

One of the main strengths of the imaging analysis for sand is that it can produce high-resolution particle size distributions for the sand fraction, even when there is too little sand for a reliable sieve analysis (<0.0200 grams, Guy, 1969). The recent publication of the multi-frequency acoustic surrogate method (Topping and Wright, 2016) is likely to increase demand for high-resolution PSD analysis of the sand fraction because one of the inputs to the surrogate model is the d50 of the suspended-sand fraction. Suspended-sediment samples frequently have too little mass for sieve analysis of the sand fraction; imaging analysis can possibly fill this emerging need.

References

Matrox Electronic Systems, Inc., 2005, Matrox Inspector 8.0 User's Manual.

Topping, D.J., and Wright, S.A., 2016, Long-term continuous acoustical suspended-sediment measurements in rivers—Theory, application, bias, and error: U.S. Geological Survey Professional Paper 1823, 98 p., http://dx.doi.org/10.3133/pp1823.