An Automated and 'Universal' Method for Measuring Grain Size from a Digital Image of Sediment.

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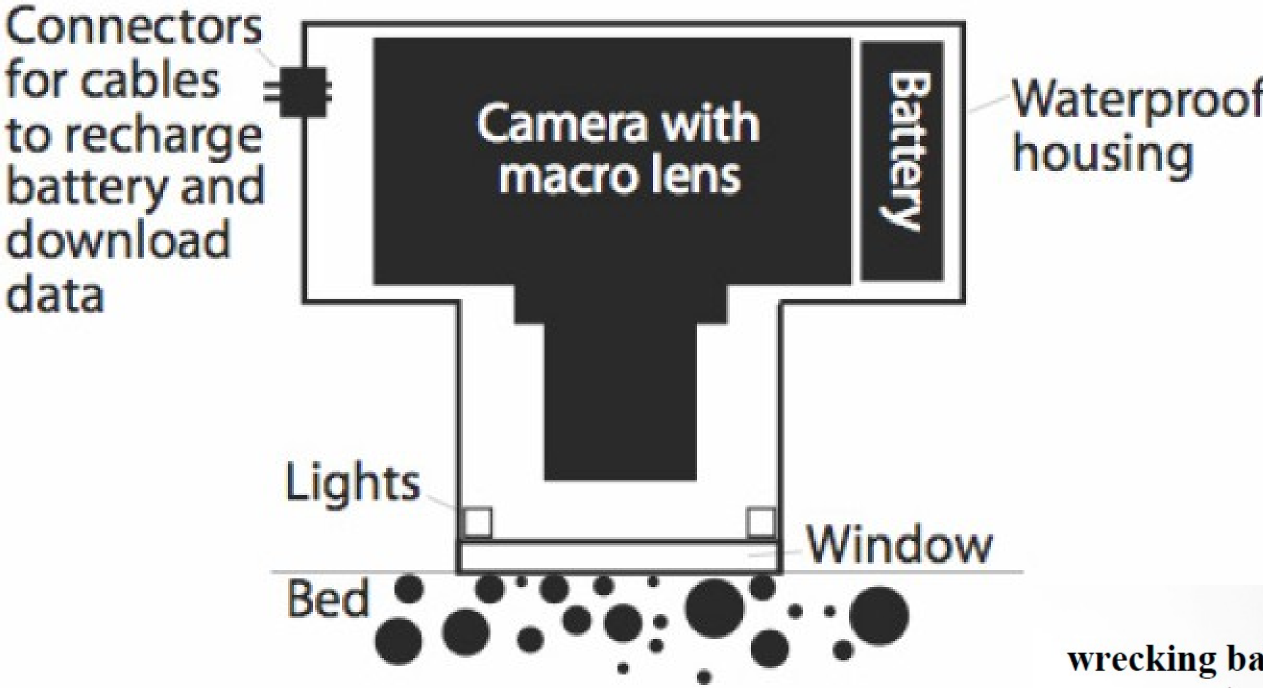
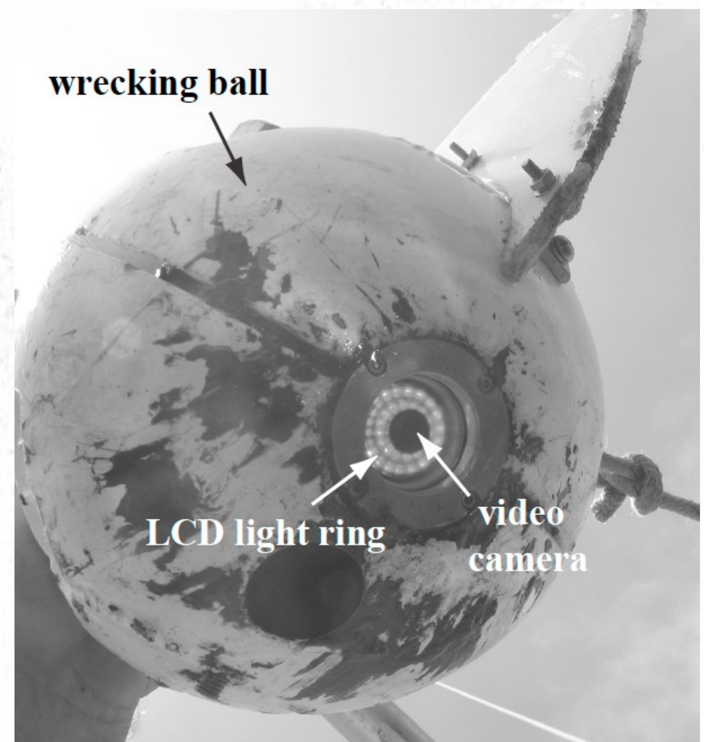
carbonate sand
beach cobble
beach gravel
beach sand


Connectors for cables to recharge battery and download data
Camera with macro lens
Battery
Waterproof housing
Lights
Window
Bed

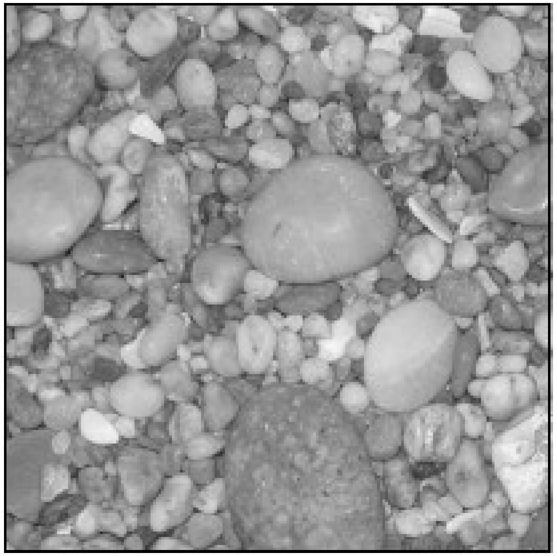

wrecking ball
LCD light ring
video camera

Previous Approaches (1)

Detect outlines of grains

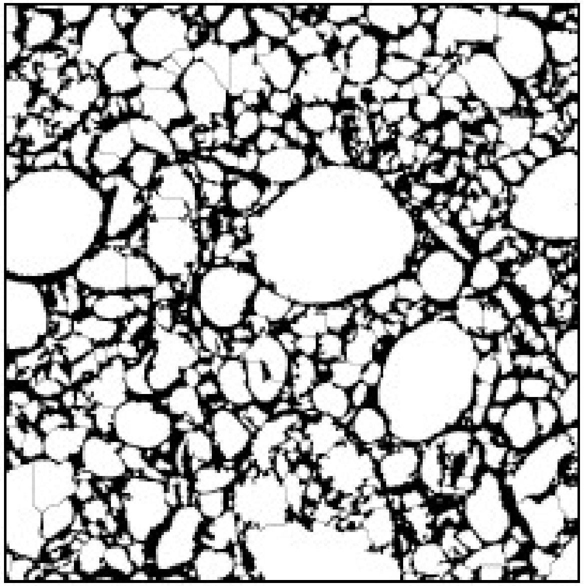
- no 'background' intensity against which to threshold

- subjective choice of filter sizes and operation sequences

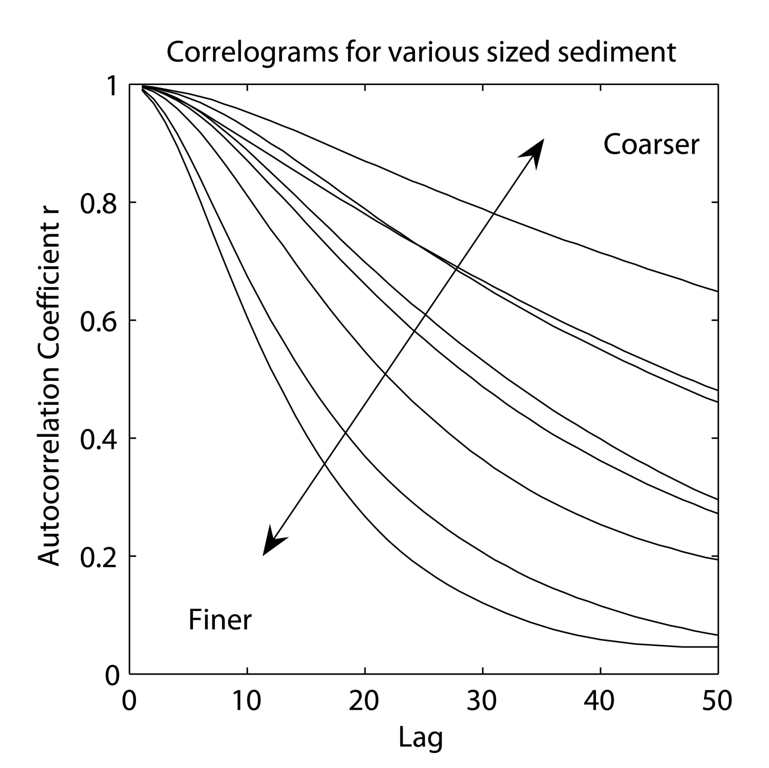


- difficult to design a 'universal' algorithm which works equally well

- non-diffuse reflectance, particle overlap, marks and scratches,etc

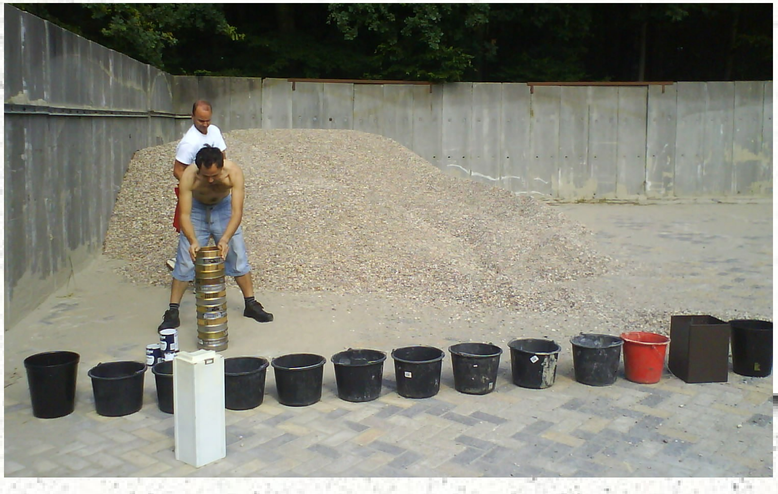


Previous Approaches (2)



- characterize features without directly measuring them

- circumnavigate problem of detecting grains



- but previous approaches rely on calibration

- errors introduced by calibration

New Approach

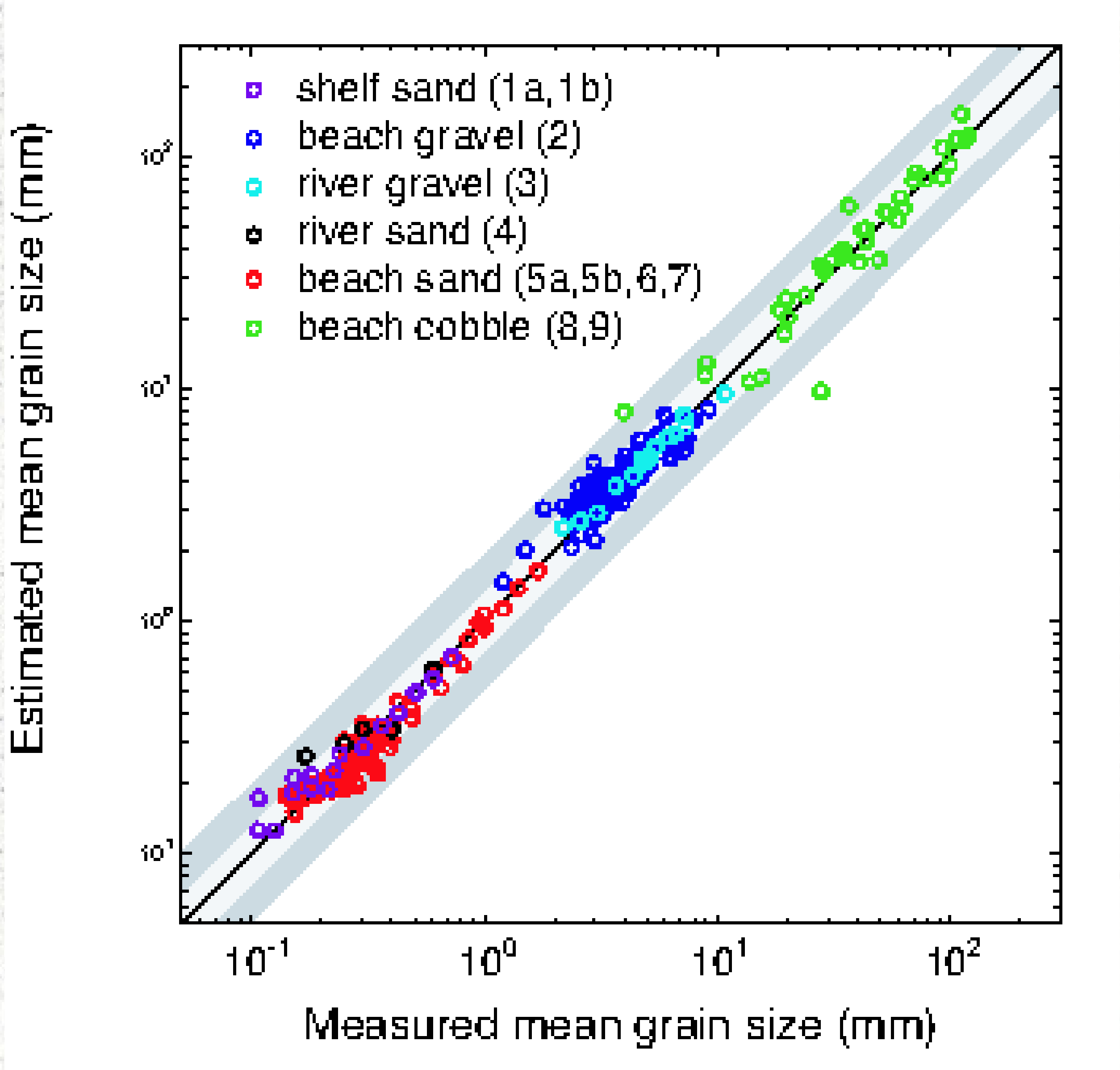
1. Requires **neither calibration nor advanced image processing** algorithms

2. **Direct statistical estimate**, grid-by-number style, of mean of all intermediate axes

3. **RMS error ~16%**, based on 500 samples from 10 different sediment environments, each with a different camera systems

4. Easy to implement (just a few lines of code)

5. Processing **takes just a few seconds**



RESULTS

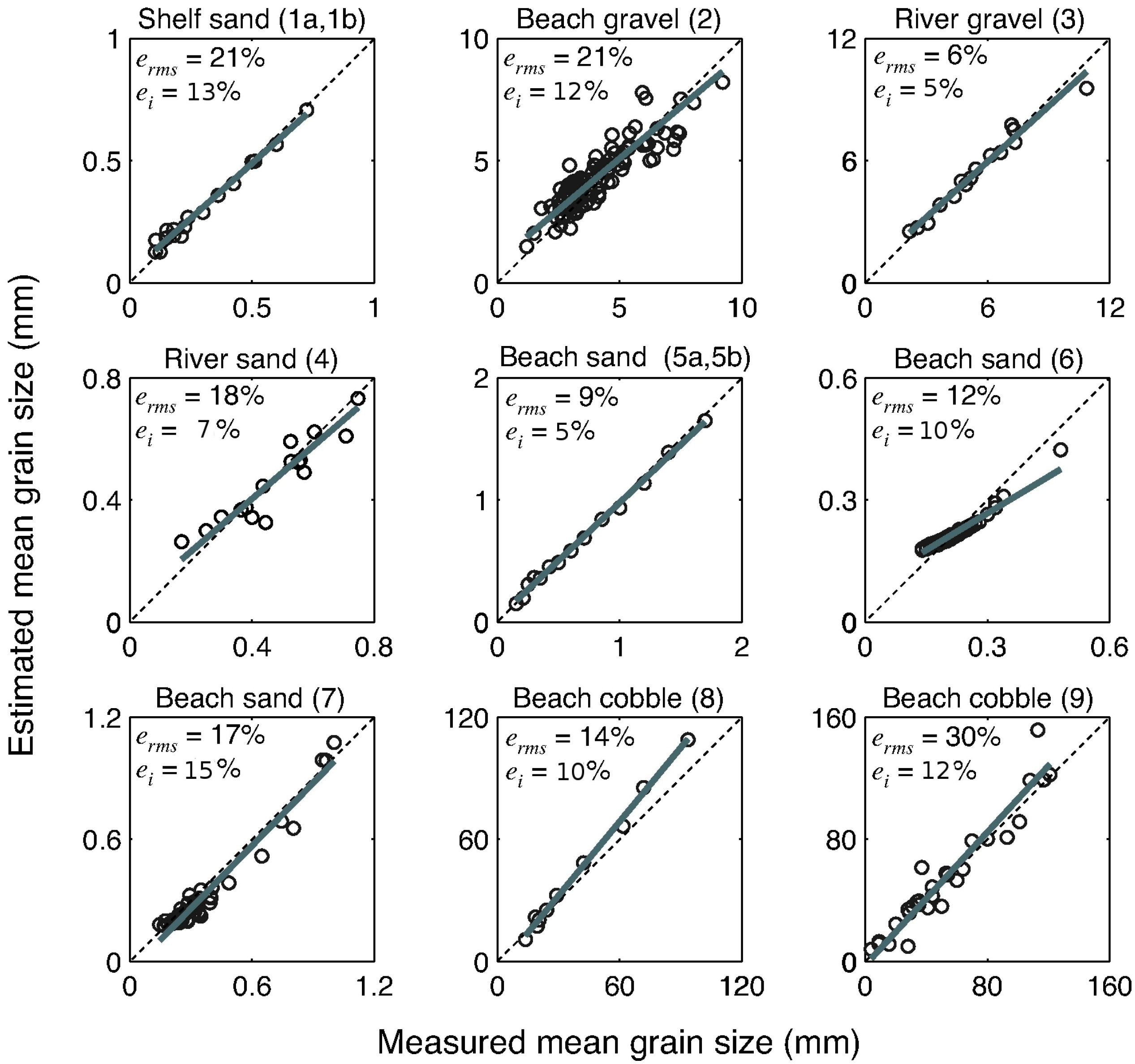
~500 images of sediment:

10 different 'populations' - each a different camera/lighting system

Range of sizes **0.1 - 150mm**

RMA-RMS error ~16%

95% chance of being within 32% of true mean



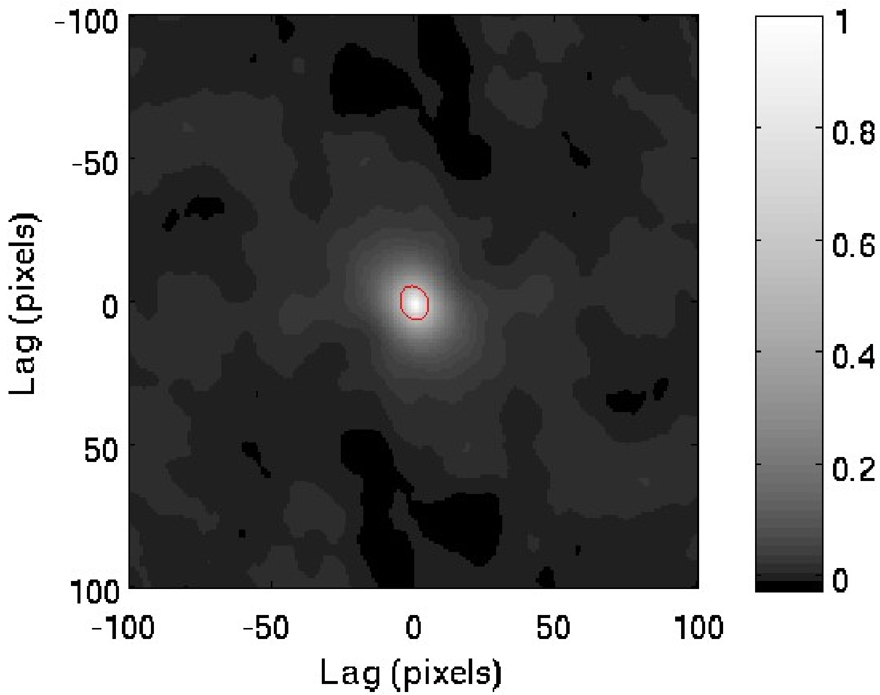
Error ~11% if corrected for bias

Individual populations can be lower

Bias correction can be achieved by 'point counts' on end members of population

Depends on sorting, quality of lighting, & number of grains

METHOD



(1)Demean image

(2)FFT

(3)Take modulus and square

(4)Normalize by maximum

(5)Find contour 0.5

(6)Radial average

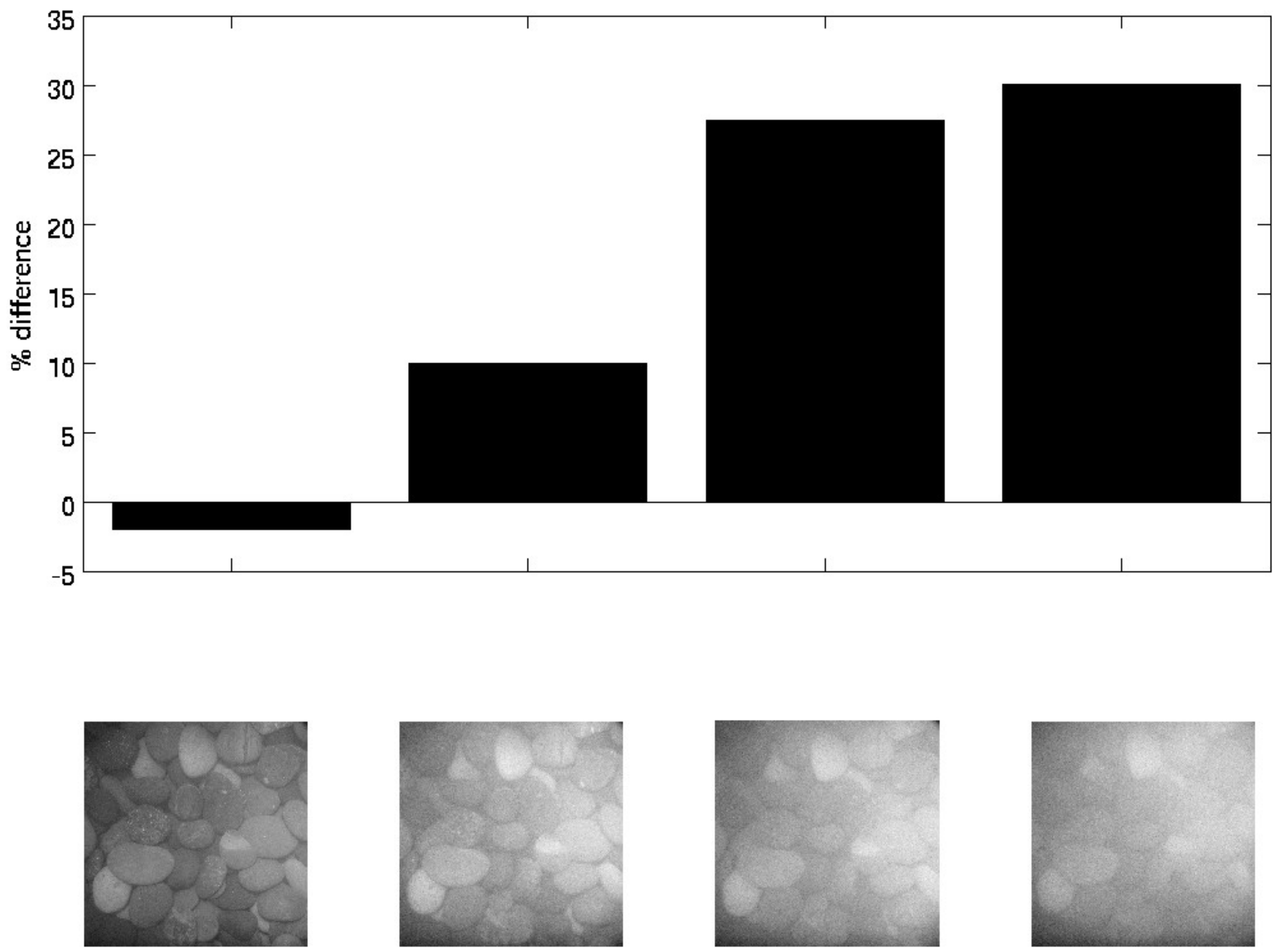
(7)'Typical' wavenumber k

$$z = 2\pi k r$$

mean grain size

TECHNIQUE WORKS EVEN WHEN SEDIMENT IMAGED THROUGH WATER

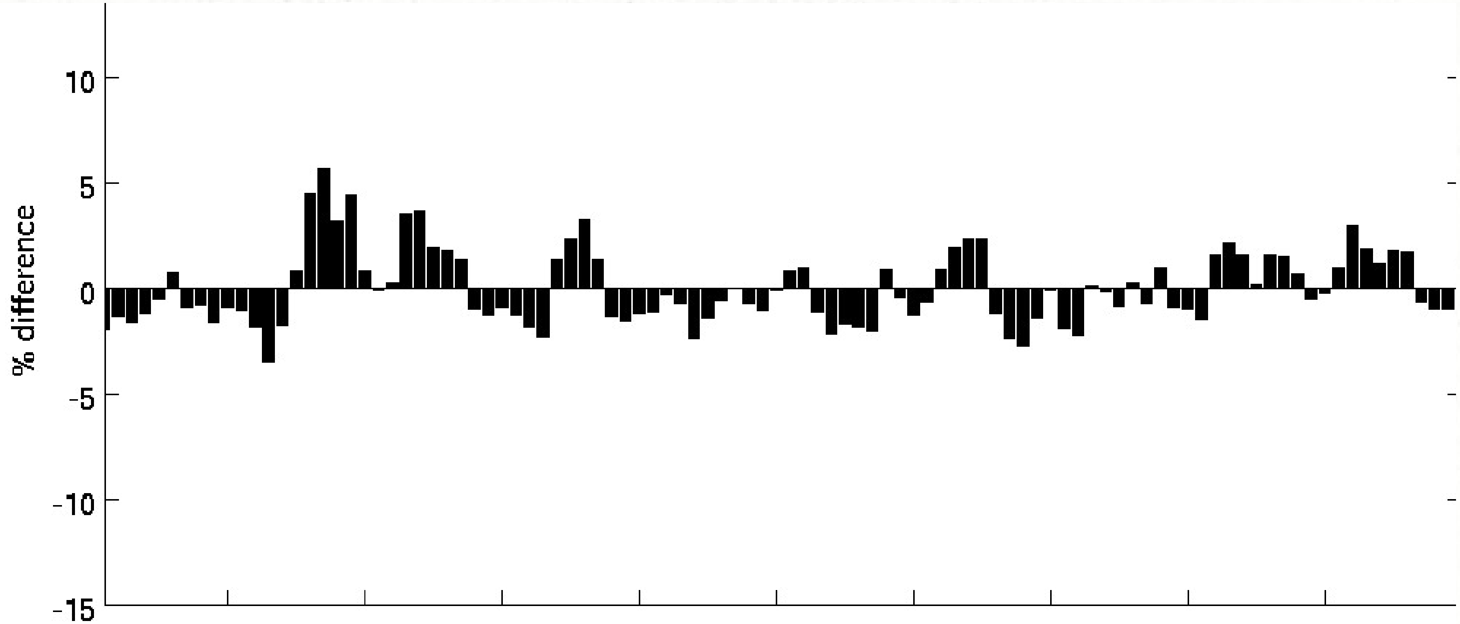
BUT ONLY IN LOW TURBIDITIES

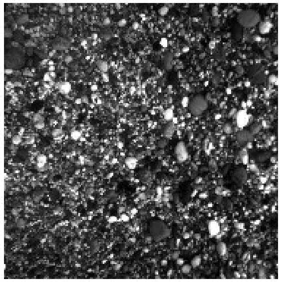
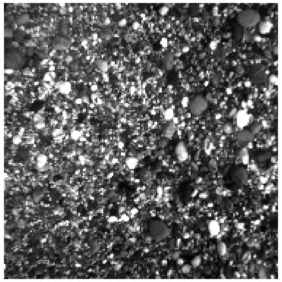
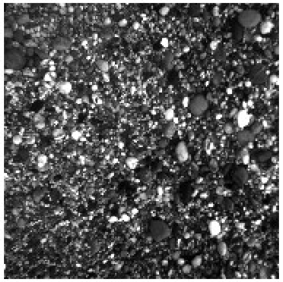
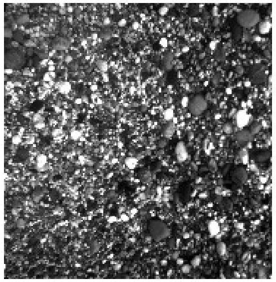


Effect of turbidity – 0, 3.31, 5.38 and 10.31 MG/L

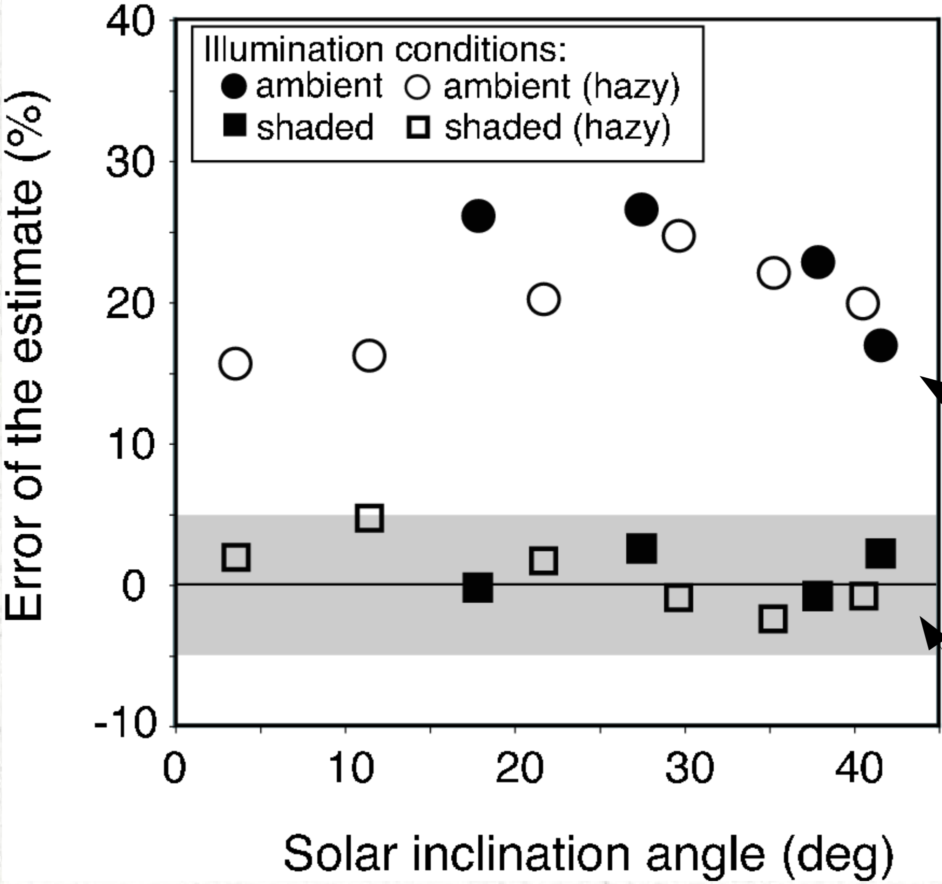
RANDOM LIGHT SCATTERING HAS VERY LITTLE EFFECT

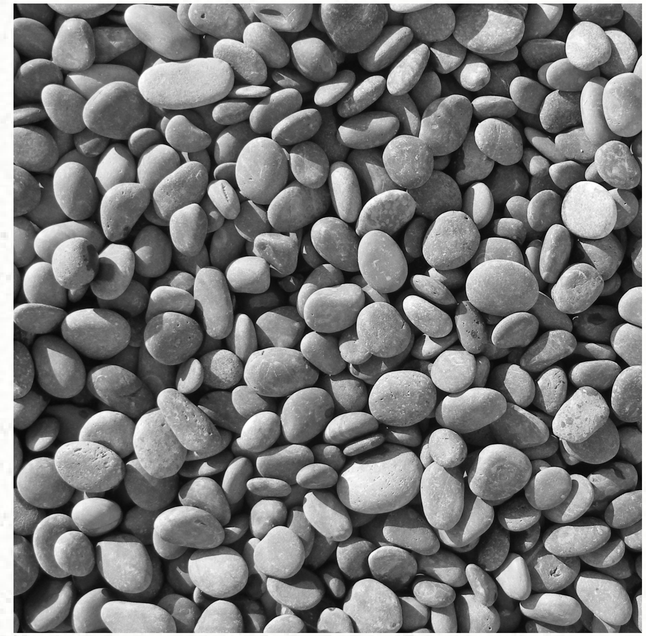
Sequence of 100 images taken underwater

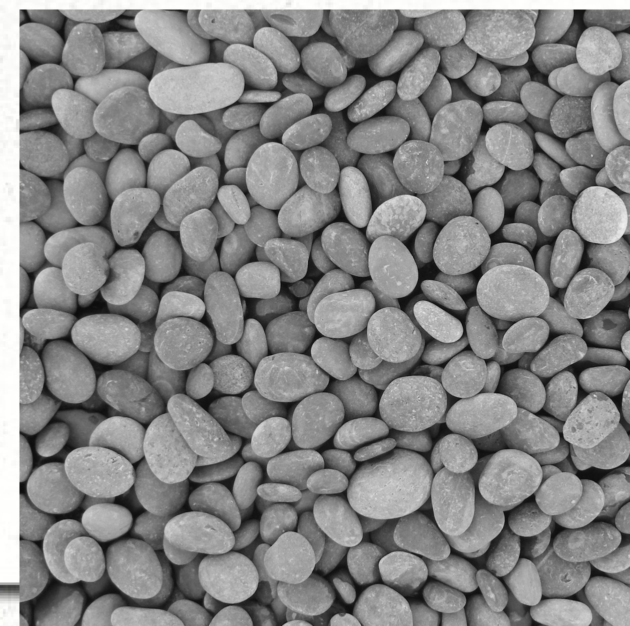


SUNLIGHT & SHADE







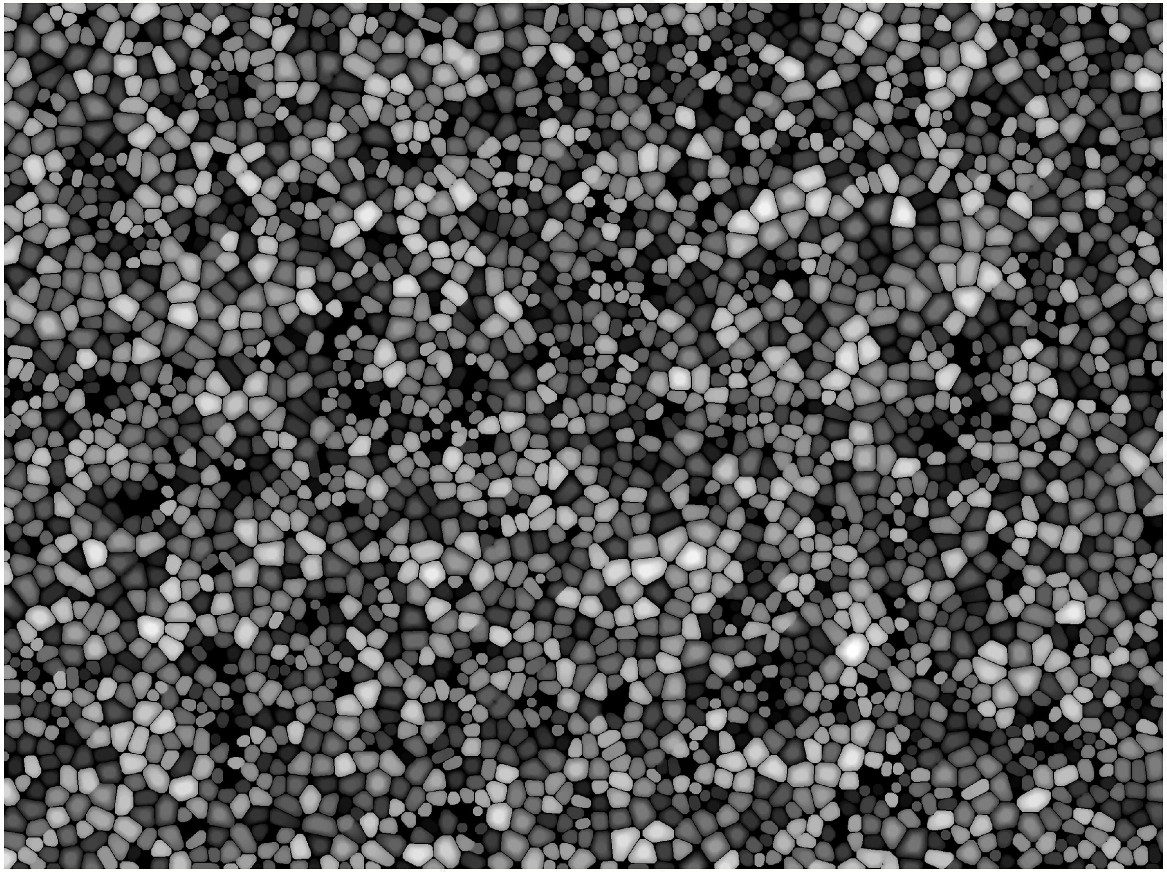
Strong sunlight – big effect

Shaded grains – very small effect

Error independent of solar inclination (at low latitude)

Computer Simulations

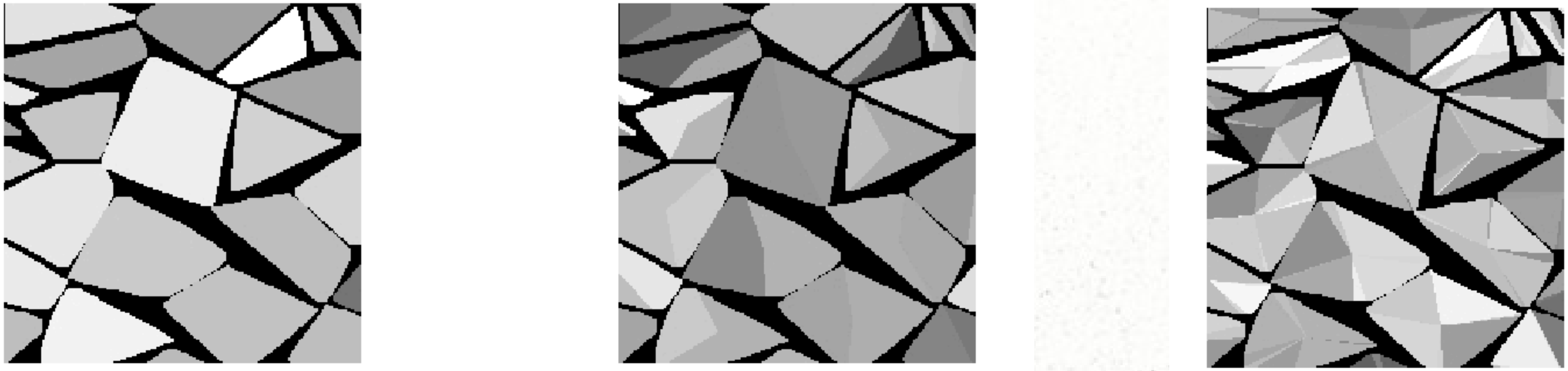
Test & explore limits of the technique



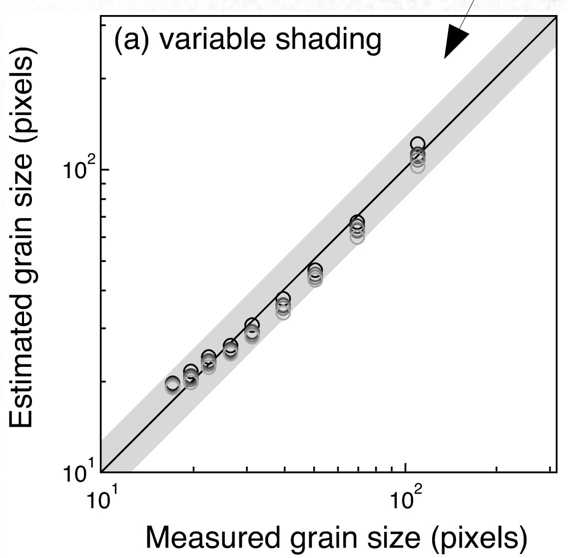
- theory

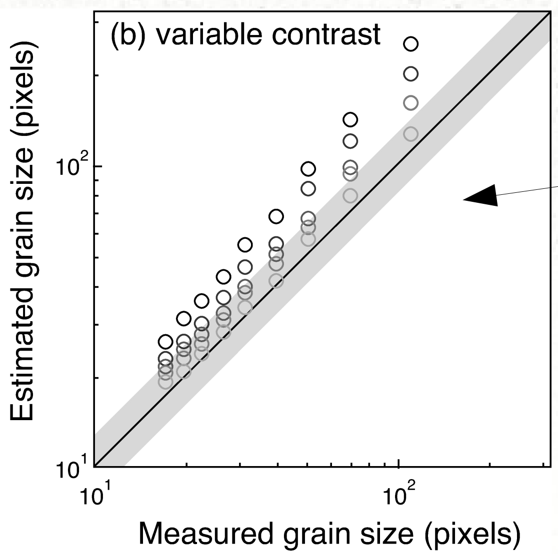
- intra-granular shading (random, tapered, uniform, etc)

- inter-granular shading (contrast between grains and pores)



Variable intra-grain (e.g. above) shading causes 5-10% discrepancies





Variable inter-grain shading causes discrepancies up to 100%

LIGHTING MORE IMPORTANT THAN GRAIN TEXTURE

More Technical Details

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, F02015, doi:10.1029/2009JF001477, 2010

A universal approximation of grain size from images of noncohesive sediment

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[1] The two-dimensional spectral decomposition of an image of sediment provides a direct statistical estimate, grid-by-number style, of the mean of all intermediate axes of all single particles within the image. We develop and test this new method which, unlike existing techniques, requires neither image processing algorithms for detection and measurement of individual grains, nor calibration. The only information required of the operator is the spatial resolution of the image. The method is tested with images of bed sediment from nine different sedimentary environments (five beaches, three rivers, and one continental shelf), across the range 0.1 mm to 150 mm, taken in air and underwater. Each population was photographed using a different camera and lighting conditions. We term it a "universal approximation" because it has produced accurate estimates for all populations we have tested it with, without calibration. We use three approaches (theory, computational experiments, and physical experiments) to both understand and explore the sensitivities and limits of this new method. Based on 443 samples, the root-mean-squared (RMS) error between size estimates from the new method and known mean grain size (obtained from point counts on the image) was found to be $\pm\approx$16%, with a 95% probability of estimates within $\pm$31% of the true mean grain size (measured in a linear scale). The RMS error reduces to $\approx$11%, with a 95% probability of estimates within $\pm$20% of the true mean grain size if point counts from a few images are used to correct bias for a specific population of sediment images. It thus appears it is transferable between sedimentary populations with different grain size, but factors such as particle shape and packing may introduce bias which may need to be calibrated for. For the first time, an attempt has been made to mathematically relate the spatial distribution of pixel intensity within the image of sediment to the grain size.

Citation: Buscombe, D., D. M. Rubin, and J. A. Warrick (2010), A universal approximation of grain size from images of noncohesive sediment, *J. Geophys. Res.*, *115*, F02015, doi:10.1029/2009JF001477.

1. Introduction

[2] Grain size is of fundamental importance, governing the mechanical, electrical and fluid dynamic properties of sediment. The surface texture of a noncohesive, unlithified sediment bed, as sensed by a photographic device, is the two-dimensional projection of its three-dimensional structure. Using photographs to quantify grain size (and other properties) of ancient or modern sediment beds, in an automated fashion, is of considerable interest because it is relatively cheap and rapid, and thus can allow much greater coverage and resolution of grain size measurements compared to traditional methods [*Rubin*, 2004]. This is because measurements from digital images are orders of magnitude faster than physical measurements such as sieving and settling [*Barnard et al.*, 2007]. In addition, measurements are nonintrusive and sample only those grains that are exposed to the flow and are thus subject to transport or winnowing.

[3] Images of natural sediment beds are complex, typically composed of at least several hundred individual grains all varying in area, form, angularity, color, etc. In addition, grains overlap and this casts shadows across the surface which are irregular in size and spatially random in color. Existing methods of automated grain size estimation from images rely on calibration [e.g., *Rubin*, 2004; *Carbonneau et al.*, 2004, 2005; *Verdú et al.*, 2005; *Buscombe et al.*, 2008], or on advanced sequences of image processing to isolate and measure each individual grain [e.g., *Graham et al.*, 2005], or both, which are often sediment population specific. In this contribution, we describe a new method for estimating mean grain size from an image which overcomes both these disadvantages.

[4] The problem of accurate and automated grain size estimation from an image of natural sediment can be

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Buscombe, D., Rubin, D.M., & Warrick, J.A (2010)

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Summary

1. **Direct statistical estimate**, grid-by-number style, of mean of all intermediate axes

2. **No calibration**, no complicated image-processing (edge detection); fast, easy to implement

3. **Typical RMS 16%**, lower if corrected for bias (involves some manual point counts on images). Well and poorly sorted sediments

4. Contrast between grains and pores more important than variation in grain textures

5. Uniformly lighted; well shaded; low turbidities

THANKS

Jessie Lacy, Parker Allwardt, Curt Storlazzi (USGS Santa Cruz)

Cristina Lira (Instituto Superior Tecnico, Lisbon, Portugal)

Marta Rufino (IPIMAR, Portugal)

SOFTWARE

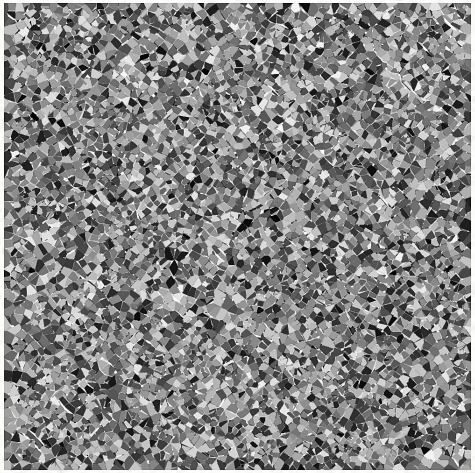
Available in MATLAB/Octave, R, & Python

Email: daniel.buscombe@plymouth.ac.uk

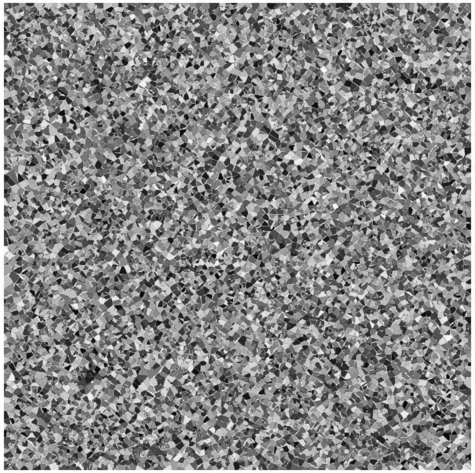
What's Next?

1,000 grains

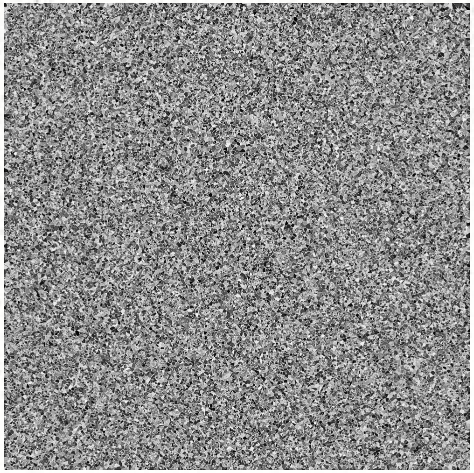
5,000 grains



10,000 grains



20,000 grains



Many different types of sediment simulations

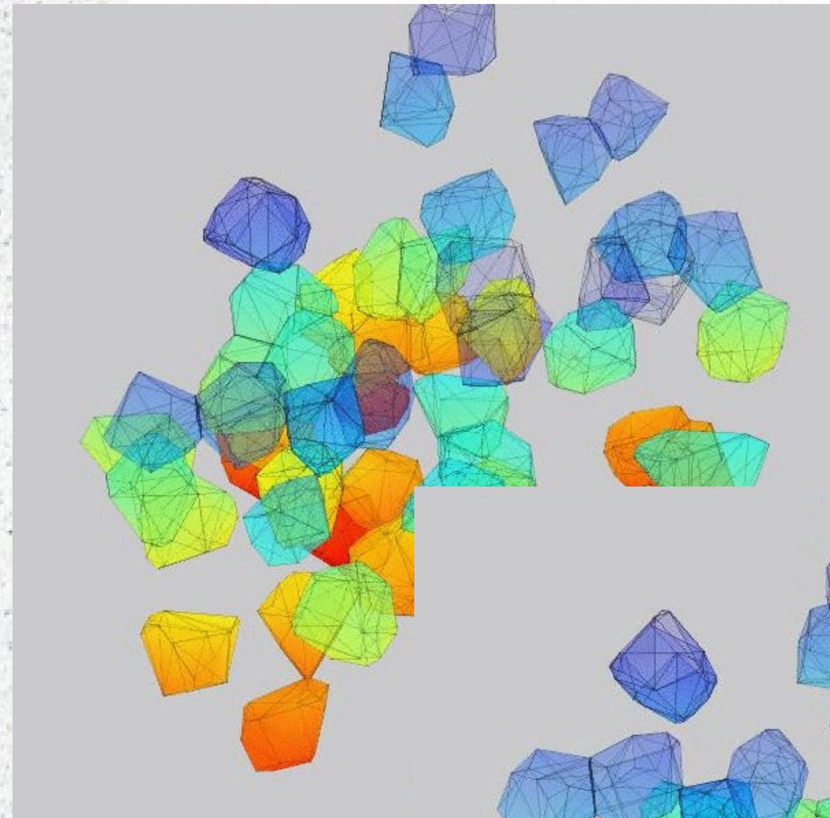
- Size/Sorting
- Shape
- Packing
- Porosity
- Mineralogy (shade)

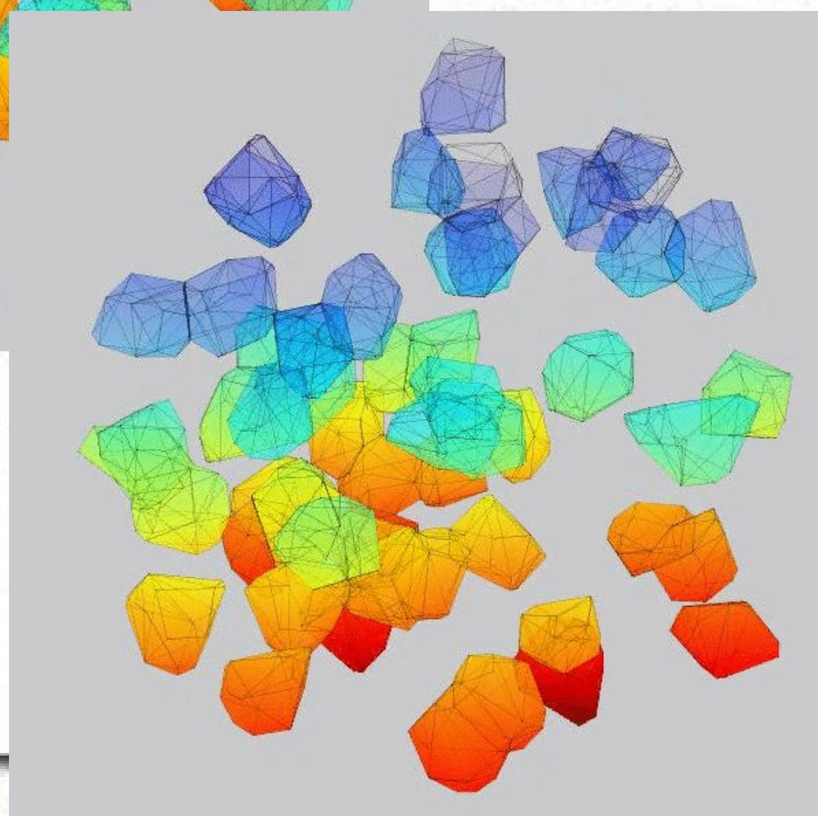
Known statistical geometries

Unconsolidated and consolidated sediments

2D and 3D

What's Next?





1. 'Universal' Sorting Coefficient

2. Real versus apparent size distributions

3. Permeability & Conductivity from Statistically-derived geometric properties

4. Discrete particle models with realistic sediment shapes

A note on image resolution

Greatest decrease in image standard deviation per unit downsample rate

Image under-resolved when R(1)<= sqrt(.5)

Minimum k = 2-3 pixels