PIV for Peanuts - a Low Cost Particle Image Velocimetry System to Observe Terminal Velocity in Suspensions

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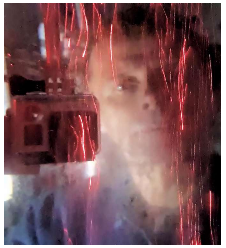

PRESENTED AT:

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MOTIVATION

In the best of times, good quality measurement of suspended particle motion can be prohibitively costly, but in these worst of times, access to suitably equipped research facilities has also been severely limited. So we found ourselves having to improvise. "With a little bit of imagination, anything is possible" (MacGyver).

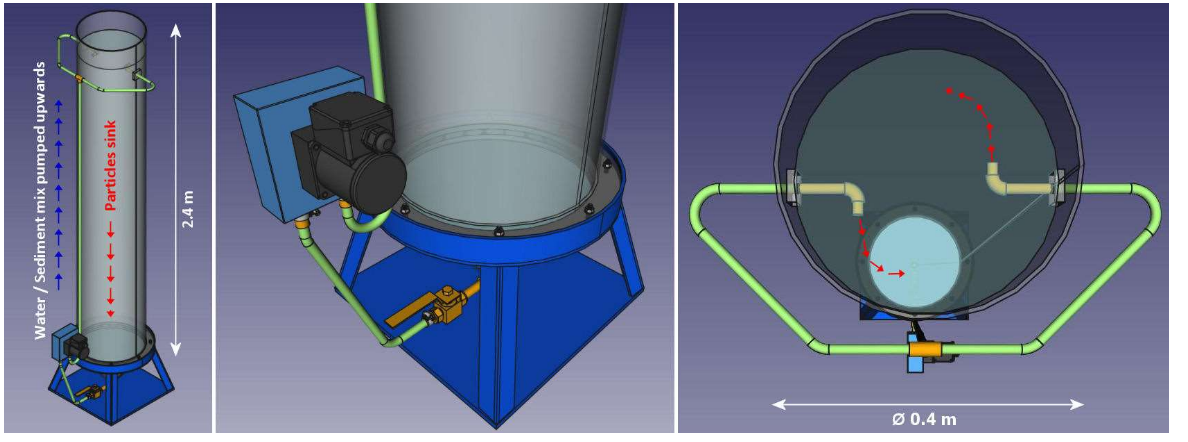
Our motivation is to gain an understanding of the velocity of particles in suspension. In creeping flow, particle terminal velocity is a function of density and diameter. In lakes, rivers and seas, velocity measurement can provide insight into buoyancy, flocculation processes and turbulent resuspension of sediment. In industry it aids understanding of processes involving precipitation of suspended solids, including mining and effluent treatment. However, it is difficult to measure directly *in situ*, especially without disturbing the measurement environment.

We are working with high-frequency acoustics. We want to improve the measurement capabilities of a commercial multi-frequency acoustic backscatter profiler, the AQUA*scat* (https://www.aquatecgroup.com/aquascat/aquascat-1000r)®. Measurement and analysis of acoustic backscatter intensity from suspensions of particles in liquids is an established technique to evaluate characteristics of the suspended material. The use of multiple incident frequencies can provide sufficient information to estimate profiles of mean particle size and suspended load over depth (Thorne and Hanes, 2002). We have developed new techniques to measure along-beam velocity using the acoustic backscatter signals (Smerdon, 2020) and need to validate them.

To achieve this validation, we chose the Particle Image Velocimetry (PIV) technique. It relies on analysis of the changes across successive frames of an image time series to derive the velocity field of particles that appear in successive images. The output is a map of velocity vectors that can be compared with our acoustic measurements.

CONFIGURATION

Limited by what could be found lying around in cupboards, we located and deployed a Bosch DIY Laser Level (Model PCL 20) and an ageing GoPro Hero 3+ video camera (see central panel) in our cylindrical, clear Perspex sediment tower, located at Aquatec Group, UK .



Aquatec Sediment Tower

The tower (see above) measures 2.5 m deep by 0.4 m diameter. It has a recirculating pump that draws sediment from the bottom and reintroduces it at the top with sufficient turbulence to create a homogeneous suspension.

The laser level was placed outside the tank to introduce a vertical light sheet through the clear tank wall. The GoPro video camera was deployed inside the tank on the end of a selfie stick, secured with duct tape. The camera was set to 15 fps, 4k video for optimum resolution and exposure in the low intensity laser light sheet. By placing the back of the camera in contact with the wall of the tank, it was possible to control it via WiFi using the GoPro mobile app. The recorded video data was then downloaded and split into frames before being processed in the open source PIVlab package (Thielicke & Stamhuis, 2014).

MacGyver PIV setup in clear perspex sediment tower
Laser level top left, GoPro top right, GoPro App and other essentials bottom left

Measuring particle flows with
PIV: P*article* I*mage* V*elocimetry*
doesn't have to cost the earth!

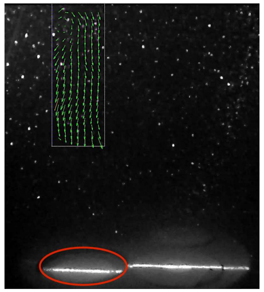
We MacGyvered a PIV setup
from a *Bosch Laser Level*, an
ageing *GoPro Hero 3+ Camera*
and the open source *PIVlab*
package

+

+ PIVlab

= **PIV for**

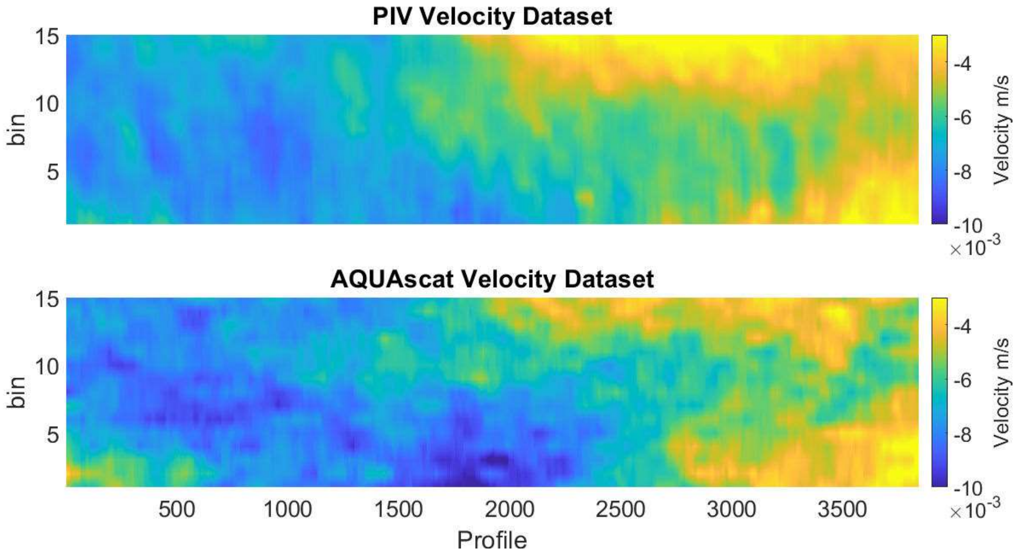
RESULTS



This frame from the video with overlaid PIV flows shows the 1 MHz upward-looking AQUA*scat* transducer, circled in red.

PIV processing was constrained to the region directly above the transducer corresponding approximately to the acoustic beam cross-section.

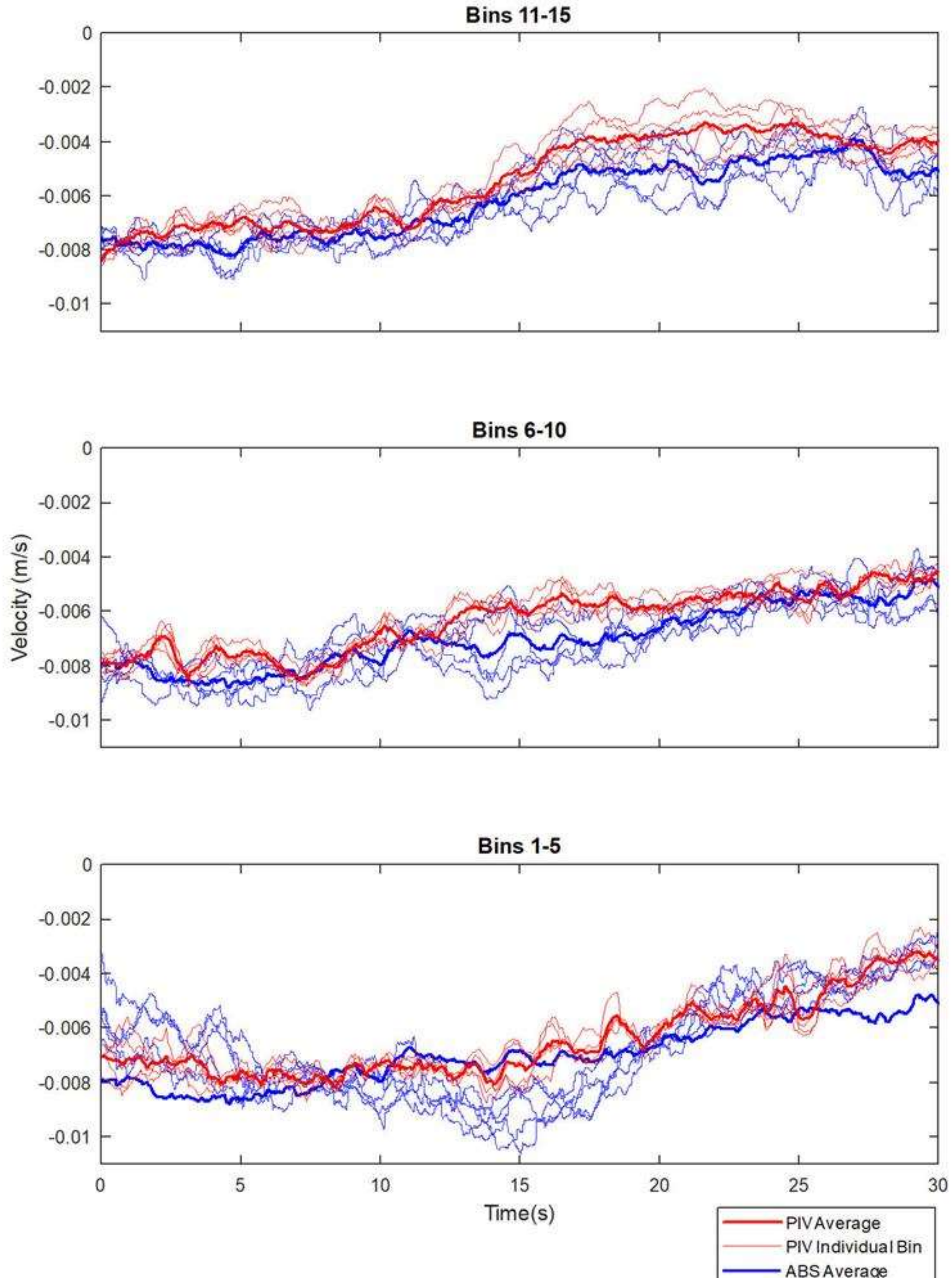
As can be seen from the flow lines in the image above, although there is a general downward settling flow, there is a clear turbulent eddy to the top left of the analysed region.



Comparison of PIV and acoustic profile time series

Velocity profiles from the 1 MHz AQUA*scat* acoustic transducer and the PIV system are compared in the intensity plot above. A data set of 30 seconds of samples of fifteen 2.5 mm bins at 128 Hz (3840 profiles) is plotted with profile number on the x-axis, bin number on the y-axis, and velocity as intensity for both PIV and acoustic data. The plots are in good general agreement in these initial experimental results.

Below, the time series of velocity from PIV and acoustic methods are plotted in groups of 5 bins for clarity. Again the good general agreement can be seen, although there is a small bias for the acoustic data to be slightly lower than the PIV data.

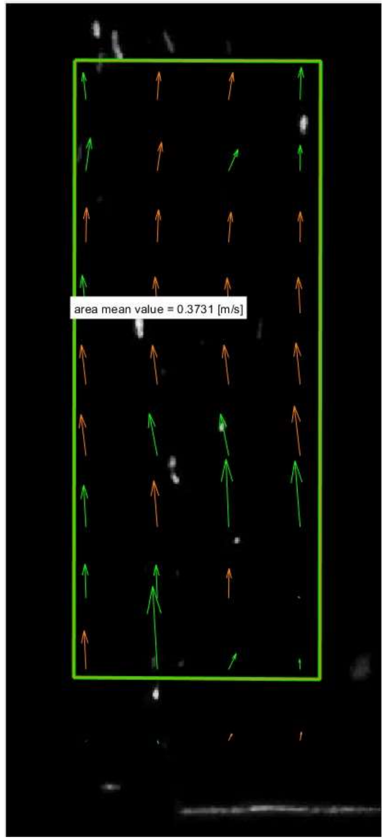


Bins 11-15
Bins 6-10
Bins 1-5
Velocity (m/s)
Time(s)
0
-0.002
-0.004
-0.006
-0.008
-0.01
0
5
10
15
20
25
30
PIV Average
PIV Individual Bin
ABS Average

Comparison of PIV and acoustic velocity time series by bin

Bubbles

This PIV system can also be used to measure the terminal velocity of rising bubbles. In a series of experiments described in another poster (/default.aspx?s=2F-DE-DB-69-05-15-B9-62-15-5A-16-E9-9C-86-81-2E&guestview=true) in this conference, air bubbles were released into the same sediment tower. In the image below, bubbles were released from an aquarium air stone, just 0.5 m below the surface, rising at a rate approaching 0.4 m/s.



To capture the larger bubbles with sufficiently low blur to allow for PIVlab processing, the frame rate was increased to 100 frames per second, with a decreased resolution of 1280 x 960 pixels.

DISCUSSION AND FURTHER WORK

While commercial PIV systems with high-powered lasers and high-speed cameras can undoubtedly perform better than our MacGyvered system, our approach offers an accessible and inexpensive fluid motion analysis solution for the classroom and small laboratory.

Our system does have limitations due to the low laser power and consequent slow frame rate needed to achieve sufficient exposure to capture images of finer or faster moving particles. Recent experiments with bubbles highlight this limitation.

The slow shutter speed used for adequate exposure of sediment particles in the relatively weak laser light sheet does not freeze the images of rapidly rising bubbles. Instead, unlike the slow-moving sediment particles on the right hand side of the image, the rapidly rising bubbles appear as near linear streaks of light, which PIVlab is unable to process.

Knowledge of the camera shutter speed in each frame potentially allows the streaks to be converted directly to velocity vectors. Fortunately the bubbles in this instance were large enough to be captured at a coarser pixel resolution and much faster frame rate as can be seen in the results section.

For researchers and educators seeking to emulate this approach there are several options. For underwater camera placement, multiple generations of original and emulated GoPro technology are inexpensively resold on eBay. For flat-sided tanks, current generation cellphones deployed outside the tank are likely to have better optical performance than the GoPro Hero 3 that we used.

Our laser level uses red light, although green laser levels are also commonplace. Red light is typically absorbed more than green light by water, so a green device of the same optical power should be more effective. Laser pens that can produce a linear diffraction pattern are an economical alternative, but need rigid mounting to achieve the same beam stability provided by the laser levelling function.

In conclusion, we offer this well worn advice: "If you don't have the right equipment for the job, you just have to make it yourself" (MacGyver).

ABSTRACT

Particle Image Velocimetry (PIV) is a proven technique for the observation of flow or particle motion in fluids. A pulsed laser is used to create a thin plane of light in the fluid, which typically contains a suspension of neutrally buoyant tracer particles. A high speed camera captures a sequence of images, which are processed to develop velocity vector fields from the particle motion.

During a wider study into the observation of particle and bubble terminal velocity in water using an acoustic backscatter profiler in a recirculating sediment tower, the acoustic data appeared to reveal a more complex flow regime than expected. To verify the acoustic results, PIV was selected as a potential approach to monitor particle motion in the region of the tank where acoustic observations were being made. Review of available PIV equipment showed that even systems designed for educational use would be beyond the budget of the planned experimental program.

A search of the cupboards yielded an alternative set of equipment with potential promise. A DIY laser level and an aging GoPro camera were pressed into action for a series of tests to investigate whether the combined equipment would be sufficiently sensitive and rapid to capture the particle motion satisfactorily. It would.

This paper describes the equipment configuration and the range of measurements achieved. Results from data processed with the open source PIVlab software tool are presented in the context of validating acoustic measurements of particle terminal velocity.

REFERENCES

Smerdon, A. (2020). Measurements of Settling Velocity with an Acoustic Backscatter Instrument. In *AGU Ocean Sciences Meeting 2020, San Diego*, San Diego.

Thielicke, W. and Stamhuis, E. J. (2014). PIVlab - Towards User-friendly, Affordable and Accurate Digital Particle Image Velocimetry in MATLAB. *Journal of Open Research Software*, 2

Thorne, P. D. and Hanes, D. M. (2002). A review of acoustic measurement of small-scale sediment processes. *Continental Shelf Research*, 22 (4), pp. 603-632.