RE-EVALUATION OF IMAGE ANALYSIS FOR SEDIMENTARY PROCESSES RESEARCH

Katherine Heays[1], Heide Friedrich [1]
and Bruce W. Melville [1]

[1] The University of Auckland Postgraduate Student, Dept Civil and Environmental Engineering, The University of Auckland, Private Bag 92019, Auckland, New Zealand. (K.Heays Tel: 64-9-3737599-89555, E-mail: khea021@aucklanduni.ac.nz)

Abstract

Sedimentary processes is a widely researched area. The application of photogrammetry to this field has the potential to reveal new insights about these processes. Photogrammetry is useful as it automates the analysis process, allowing in-depth investigation into vast quantities of data which would otherwise be time consuming.

Experiments have been conducted for the development of photogrammetry with the application to sediment transport research. Different sized, painted in different colours particles were used in combination with photogrammetry. An image analysis method was successfully developed to produce results regarding the quantification of surface grain size distributions over time, and for tracking the position and orientation of an individual particle over time.

Key Words: Sediment transport, Image processing, Photogrammetry, Particle tracking, Distortion

1 INTRODUCTION

Investigation into the motion of sediment particles in fluids has historically been a topic of great interest. The evolution of monitoring techniques has provided new insights which improve the base of knowledge in this field. Photogrammetry has emerged as a practical method for gathering detailed data from sedimentary motion (Moore 1976) and can be manipulated to provide indepth information regarding the surface and particle characteristics of river beds (Keshavarzy and Ball 1999; Lane et al. 2001; Schuyler and Papanicolaou 2000). Photogrammetry is the study of photographs to determine quantitative information about a subject, and is well suited to the study of sedimentary processes. This type of monitoring requires detailed observation over prolonged periods of time (Keshavarzy and Ball 1999), and can be time consuming when done manually. Previous methods have relied on observation, sieving to determine surface sizes, and manual measurement of features on photographs of the test section to identify sedimentary features (Chin 1985).

The development of image analysis algorithms allows for quick processing of long sequences of photographs. These provide output showing the behavioural trends of sediment over extended periods of time. Algorithms can be developed to investigate a number of features of sediment transport. These can be categorised into two areas of study; firstly, overall trends of sediment movement and secondly, studies of individual particles. Overall trends can be used to determine how surface formations or the grain size distribution of a river bed change with time (McEwan et al. 2000), highlighting phenomena such as armouring. Specific studies can give insights into the behaviour of sediment microforms, and are useful for the study of sediment entrainment. Specific information, such as particle velocity, can be analysed to give statistics on the properties of a bed (Li et al. 1997).

Research into sedimentary processes has commonly utilized the technique of 'tagging' particles to aid observation. Historically sediment transport studies have used radioactive and fluorescent substances to coat natural sediment in field studies (Black et al. 2007). Synthetic sediment has also been used such as coloured plastic beads (Schuyler and Papanicolaou 2000), which are desirable as they avoid the difficulty of painting the particles, however they of different specific gravity and shape to real sediment.

This paper describes the methods developed for the study of sedimentary processes in a section of a flume using photogrammetry and image analysis. Conducted experiments are introduced and results discussed. The sediment was painted with different colours to assist analysis, allowing groups of particles to be observed individually depending on size.

2 EXPERIMENTAL SETUP

Experiments were conducted in the Hydraulics Lab at The University of Auckland using a 19m long flume with dimensions 0.45 m wide by 0.5 m deep. The test section comprised of a fixed bed with a vertically adjustable recess filled with graded, rounded gravel with D_{98} = 26 mm and SI = 4. A constant flow rate of q = 0.15 m^2/s was applied to the test section and aerial photographs were taken of the test section for the duration of the experiment (Figure 1). The shear velocity was calculated to be u* = 12 cm/s.

The gravel in the test section was separated into five particle-size groups and each group was painted with a different colour to enable identification of different sized particles. The colours used for painting the rocks were chosen to be as different as possible. The colours red, white, yellow and green were used, leaving the smallest size group unpainted as grey (Figure 2). Initially blue was chosen instead of white; however analysis of the photos found that the colour difference between blue and green was too small to distinguish between them digitally. The gravels were painted using spray enamel; they were laid out flat and coated once, then left to dry, roughly turned, and sprayed again. For colours with a wide range in gravel size, the gravel was separated into two size groups and painted separately, as the smaller gravel particles tended to fall to the bottom and receive less paint coverage than the larger sized gravel. This process was repeated until sufficient coverage was achieved. Care was taken not to coat the gravel too many times as this would enlarge the gravel size, altering the grading curve. The painted gravels were mixed manually and then poured into the test section; some problem was encountered with the smallest fraction of the gravel falling quickly to the bottom. Four flood lights were used to illuminate the test area surface, with two lights on either side of the flume. The test section was equipped with an adjustable table, allowing the bed material in the test section to remain flush with the fixed bed on either side of the section throughout each experiment.

To eliminate distortion of the image from reflection and refracting light caused by fluctuations of the water surface, a 1 m long Perspex skimmer was fabricated. This ‘flow guide’ was adjustable and could be made to sit lightly on the surface of the water so that the waves were flattened but minimal disturbance was caused to the channel of water and pressurisation was minimal. One problem with the skimmer was the presence of bubbles which were created through the obstruction at the upstream end of the skimmer. These would flow under the skimmer, thus being present on the recorded images and negatively influencing the forthcoming image analysis. Consequently, these bubbles were minimised by adding an additional skimmer upstream to flatten the water entering the test section, and adding a streamlined ‘V’ shape to the upstream side of the skimmer to divert any bubbles to the edges of the skimmer, where they would not influence the image analysis.

The test section was equipped with an overhead frame on which the camera was held steady, and a tripod was set up next to the flume for a second camera to capture a side view of the test section. A Canon Powershot TX1 digital camera was chosen as an affordable, practical video camera. The video captures images at a rate of 30 fps, which is a fast enough frequency to capture most movement on the bed. The limitation with using this camera is that the flash memory for these cameras is of FAT32 format, which has a file size restriction of 4GB. Employing the camera in HD mode thus results in a maximum clip size of 4 GB per file, which translates to around 16 minutes. In addition, Canon does not support direct computer control for the Powershot TX1, thus media collection is interrupted to allow for the 4GB file size restriction. In our case the memory in use was a 16GB SDHC card, allowing interrupted capturing of 64 minutes of footage, which must be downloaded to the computer frequently when intended for longer use. This disrupts image collection and risks changing the position of the camera, thereby taking subsequent images of a slightly different section of bed and making analysis more difficult.

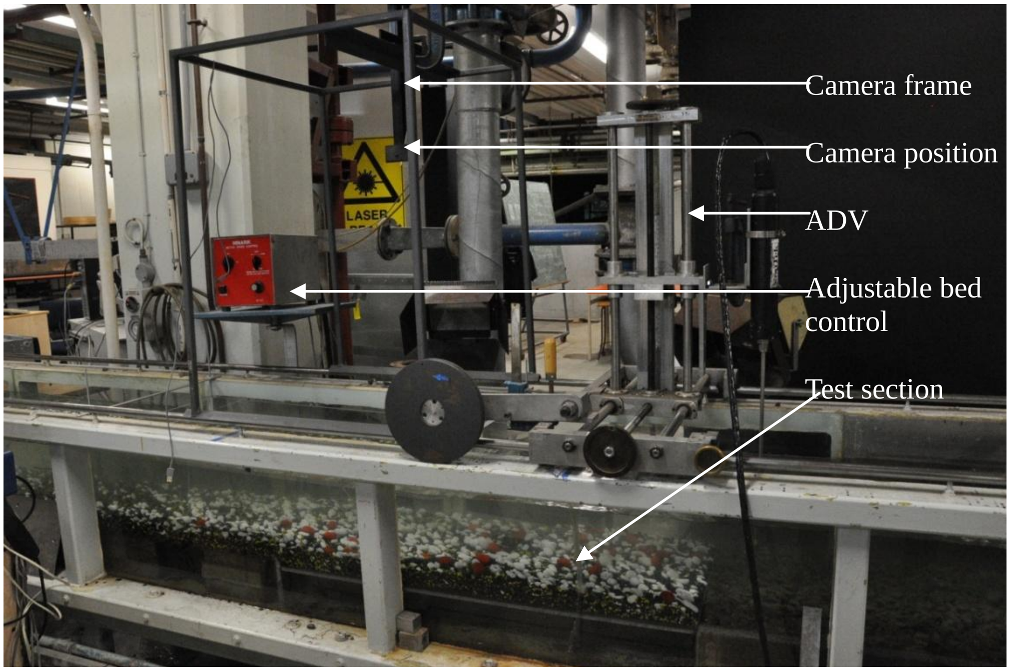

Figure 1. Flume setup

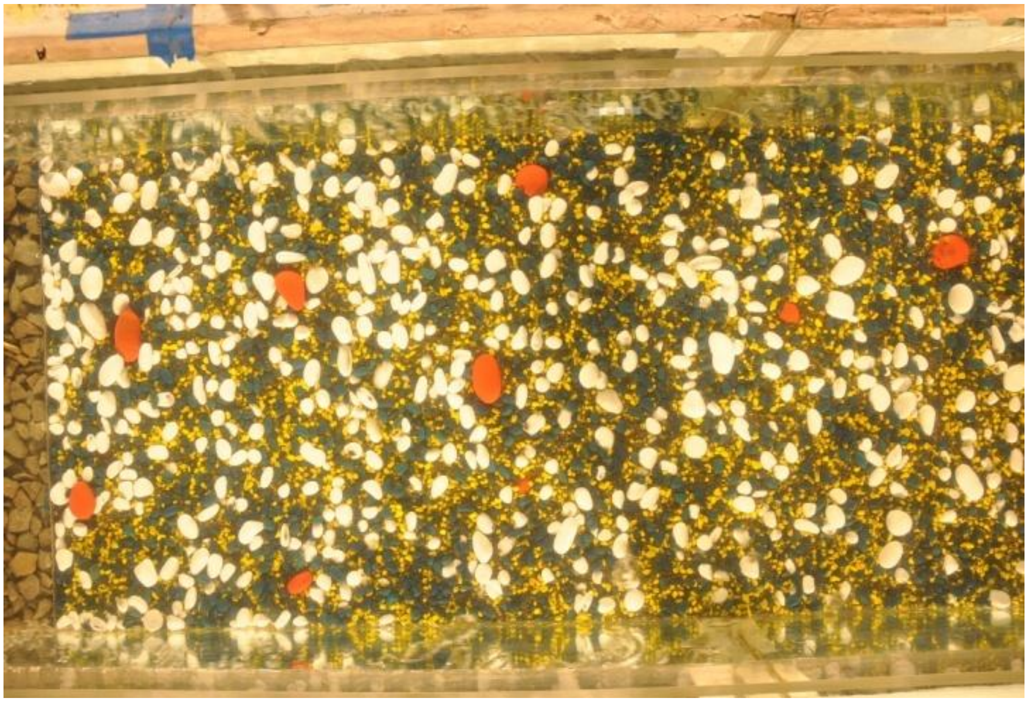

Figure 2. Test section with coloured sediment – original, distorted image.

A cost-effective solution is to use a digital SLR camera, several brands support direct computer control. We chose a Nikon D90 camera for the main experimental tests, which could be connected to a computer to allow remote control and immediate download of the image to the computer's hard drive. This camera was used to take still photos at a rate of 1 per second for the duration of the experiment which is a high enough frequency to capture the movement of larger particles in the test section.

Velocity information was obtained using an ADV probe. Velocity profiles were recorded downstream of the test section with the ADV for all tests. For test two, velocity profiles were collected at multiple positions upstream and within the test section. This facilitated the comparison of flow distributions approaching the test section with the existing flow distribution throughout the test section and the existence of uniform flow was verified.

3 IMAGE ANALYSIS

The images taken during the experiment were loaded onto the computer's hard drive either continuously when using the NikonD90 camera, or periodically during the experiment with the Canon Powershot TX1. The video footage was loaded into Image Grabber, a free software which extracts still frames from video. The main tool used for image analysis was Matlab (R2008b), for which code was written to firstly apply the calibration algorithm to the images, and then perform surface grading analysis and/or particle tracking.

3.1 Introduction to image structure

When taking a photo, cameras have a sensor array where each individual sensor gathers information to create a pixel in the captured image. Photons fall into each pixel when an image is captured, with the quantity of photons determining the resultant light intensity of that pixel. To obtain a colour image, each pixel has a filter which allows only a certain colour to enter. The colours detected are red, green or blue. The filtered pixels are arranged into a Bayer array, which has alternating rows of green-blue and green-red filters. The combination of red, green and blue intensity values for each 2x2 group of sensors is used to determine the overall colour for that pixel. The red, green and blue intensity information is available for each pixel, resulting in each image comprising of a length, width, and the red, green and blue (RGB) values for each pixel.

3.2 Image calibration

Close range photography generally results in some image distortion due to the curvature of the lens. This shows in the image as either barrel or pin cushion distortion. If being used for photogrammetry, a distorted image will yield inaccurate results and must be calibrated before analysis.

As the camera position is fixed, an image distortion equation is developed for one image in the experiment, and can then be applied to the rest of the images. The image calibration process follows six steps:

1. Create an ideal checkerboard in Matlab
2. Photograph the checkerboard grid in the test section
3. Determine the coordinates of the corners of each square of the checkerboard images
4. Compute the distance between the coordinates of the photographed and ideal images
5. Interpolate to determine displacement required for pixels between points of known displacement
6. Replot the image with altered coordinates for each pixel

Step 1: A checkerboard was generated on Matlab and used to provide a reference as to what an ideal checkerboard should look like. The checkerboard was made to be the same dimensions and with the same number of squares as the photo in step 2.

Step 2: The ideal checkerboard was then printed to create a checkerboard large enough to fill the test section. This was done immediately prior to conducting the experiment so the camera would remain in place. The checkerboard was photographed lying flat against the test section bed before the flume was filled with water. Then the checkerboard was removed, and without altering the position of the camera, the flume was filled with water and testing commenced.

Step 3: The corners of each square in the checkerboard were identified by finding the points where lines with a large intensity variation in the horizontal direction meet with lines of large intensity variation in the vertical direction. Coordinates of the corners were retrieved and placed in order.

Step 4: The coordinates of each corner in the photograph were compared with the corresponding coordinates of the same corner in the ideal image. The difference between the corners was recorded.

Step 5: To determine the displacement error in the pixels between the corners with known displacement a planar relationship was used for interpolation. Three corners of each check were used to estimate the displacement between the four points.

Step 6: This created a matrix of values showing the deviation of each pixel from the ideal straight grid. This information was used to alter the position of each pixel in a new image, creating an undistorted image.

3.3 Surface grading

Stream bed armouring effectively changes the grading curve of the sediment on the surface of the bed; reducing the amount of fines and generally coarsening the sediment. Photogrammetry can be used to measure this change in grading, allowing observation of the change in grading composition over time. Each image was analysed by the following algorithm (created with Matlab), containing four steps:

1. Identification of a region of interest (ROI) and image calibration
2. Definition of the colour ratio values for each coloured rock group
3. Isolation of each rock colour and calculation of the percentage of ROI covered by the colour
4. Plotting of the percentage coverage of each colour for each image.

Step 1: Using the image calibration derived in section 3.2, the image was undistorted. The ROI was manually defined as the area in the test section with sufficient lighting and minimal interference from the boundaries of the flow guide. As the camera is in a fixed position, this area is the same for each image, so after the initial definition of ROI boundary, the same ROI can be used for the entire batch of images.

Step 2: The RGB intensity values for each pixel were observed, and the different colour combinations for each coloured rock were determined (Figure 3). As each colour has a distinctly different combination of RGB values, each colour group can be digitally isolated. The combinations of RGB values were identified for each colour using upper and lower threshold values and ratios between the three channels.

Step 3: For each colour, the pixels with the RGB combination for that particular colour were placed in an individual matrix, this resulted in a new image being formed showing the rocks that were painted that colour. The isolated monochrome rocks image was then converted into a black and white image showing the rocks as black silhouettes on a white background. The area covered by the black space in the new image represented the percentage coverage of that particular colour over the ROI.

Step 4: The percentage coverage for each colour in each image was then recorded. These values were plotted, resulting in a graph showing how the coverage of each colour changes over time (Figure 5).

This graph is useful for demonstrating the general trend of particle movement with time. If armouring occurs, the plot will show a decrease in the percentage coverage of fines with time, and a corresponding increase in percentage coverage of larger particles. These values are used to create a rough grading curve, using the computed percentage of test area coverage for each of the five size groups as data points for the curve.

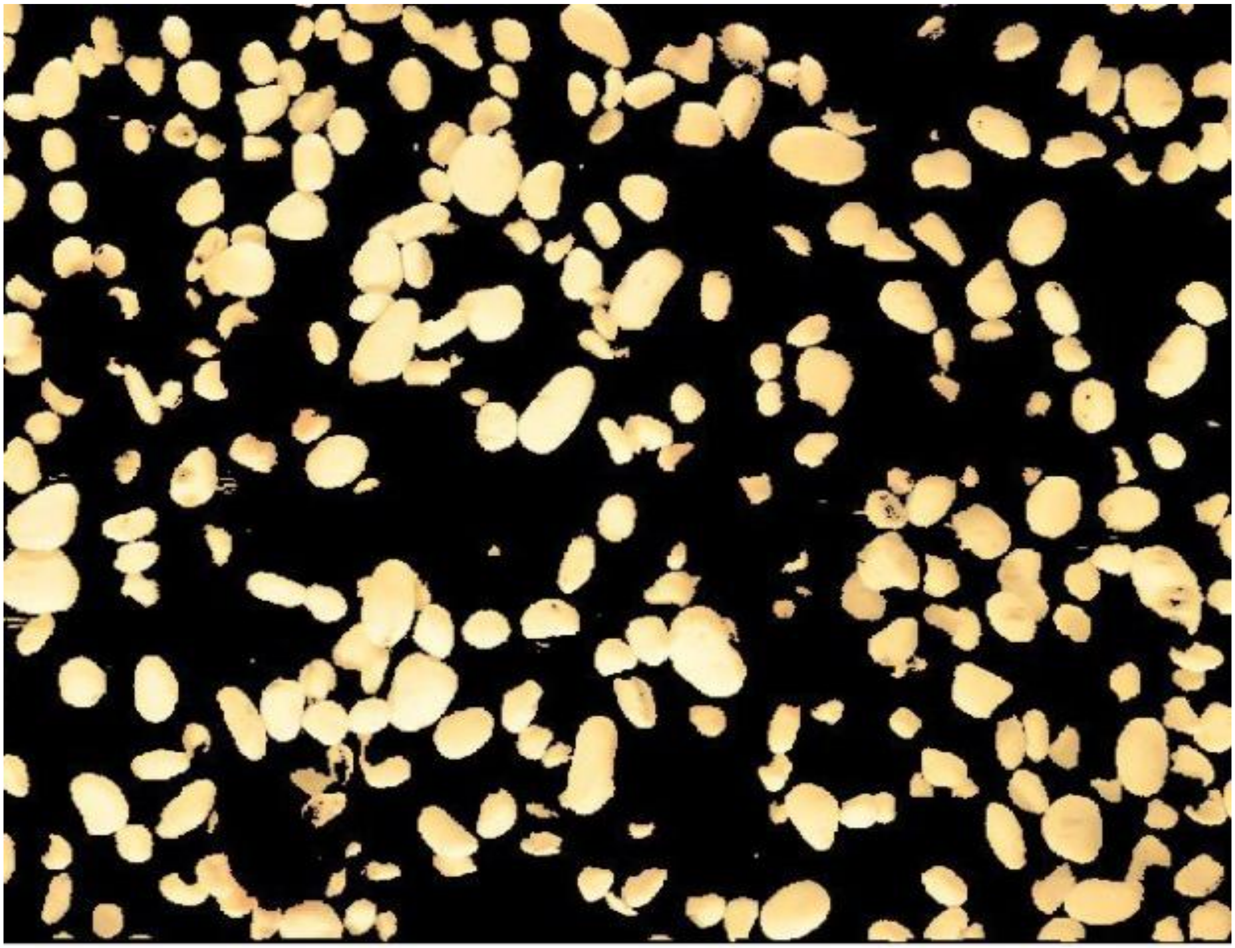

Figure 3. Step 2: Colour isolation

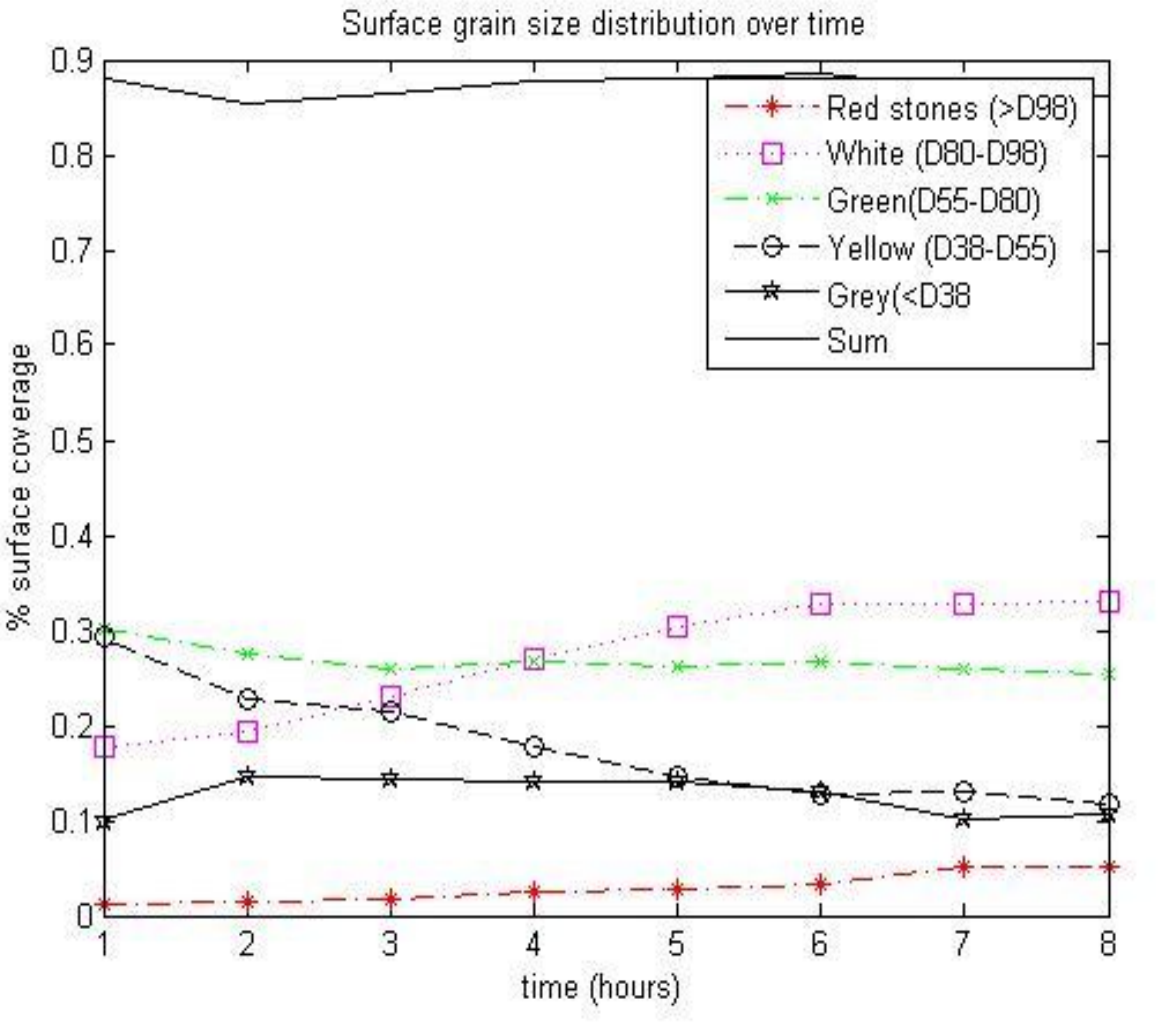

Figure 4 Output: Surface grain size distribution

3.4 Particle tracking

Analysis was undertaken to track the movement of the coloured particles. The larger particles were chosen to be tracked initially, as the presence of relatively few particles made the development of the analytical method more straightforward. The method used for this particle tracking algorithm used a pixel counting method, relying on the irregularities between particle size to identify a particular particle. The objective of this analysis was to track the movement and orientation of one particular particle as it moved throughout the duration of the experiment. This was a period of approximately 5 hours, and during this time, the observed particle moved in bursts downstream along the length of the section, taking slightly less than 5 hours to finally exit the test section.

The use of a background elimination method was incorporated into this algorithm. Two consecutive images are superimposed on each other and subtracted, effectively eliminating the background and leaving any live particles. When subtracted from each other, the same sections of two images cancel each other out, leaving values of zero. Where a lighter particle has moved and left a darker space, a positive value is recorded, and vice versa (Wang et al. 2009). This produces a series of images where only the particles that move from one frame to the next are visible. The direction and velocity of these particles can be obtained by using Particle Tracking Velocimetry (PTV).

Initially a particle tracking algorithm for Matlab was chosen, which had been developed at Georgetown University (Blair, 2005). This technique was successful at tracking particles, however over longer periods of time it was not suitable for this analysis due to the lack of identifying a target particle. This resulted in the tracking of all particles moving in the test area, producing a cluttered unclear image of the particle movement. In response to this the targeted particle tracking algorithm was developed. The particle tracking process used the following procedure:

1. Isolation of largest fraction of particles
2. Identification and measurement of a target particle
3. Specification of maximum displacement threshold for target particle
4. Image subtraction to eliminate all stationary particles
5. Pixel count of area within displacement threshold
6. Recording coordinates and orientation of target particle
7. Repeat for all images in sequence

Step 1: Isolation of the largest fraction of particle was achieved using the colour isolation algorithm, as discussed in Section 3.3. The resulting image was primarily blank, showing only the few largest particles in the test section. The image was converted to black and white.

Step 2: The target particle was identified manually and a simple pixel count command was used to count the number of pixels making up the target particle.

Step 3: The footage of the experiment was examined to estimate the maximum displacement of the target particle that would occur. This was used to create a smaller ROI proximal to the target particle, which was to be searched in the next step for the new location of the target particle. The images used in this analysis were taken at a frequency of 1 fps, resulting in a potentially large displacement of particle between frames. The need for a displacement threshold arose from the occurrence of other similarly sized particles being incorrectly detected.

Step 4: To further reduce the number of particles to be considered as the new position of the target particles, image subtraction was used. The image was subtracted from its subsequent image, leaving only particles which would not remain stationary in both images. The previous particle position was included in the case of no movement between frames, and also reverse subtraction was considered in special cases where a particle moved in the previous frame, but remained stationary in the current and subsequent frames. All of these were used to create an image with scattered ROI’s, reducing the area for analysis.

Step 5: The area within the ROI was searched and a pixel counting method used to count the numbers of pixels in any features showing in the ROI.

Step 6: The size of all of the particles detected in the ROI were compared with the size of the target particle, and the particle most similar in size was assumed to be the target particle in its subsequent position. The coordinates and orientation of the particle were gathered to show the movement with time.

Step 7: The process was then repeated using the new position of the target particle as a starting point for the method.

This method was found to be successful for tracking the particles of interest; the output from one sequence of images can be seen in Figure 5.

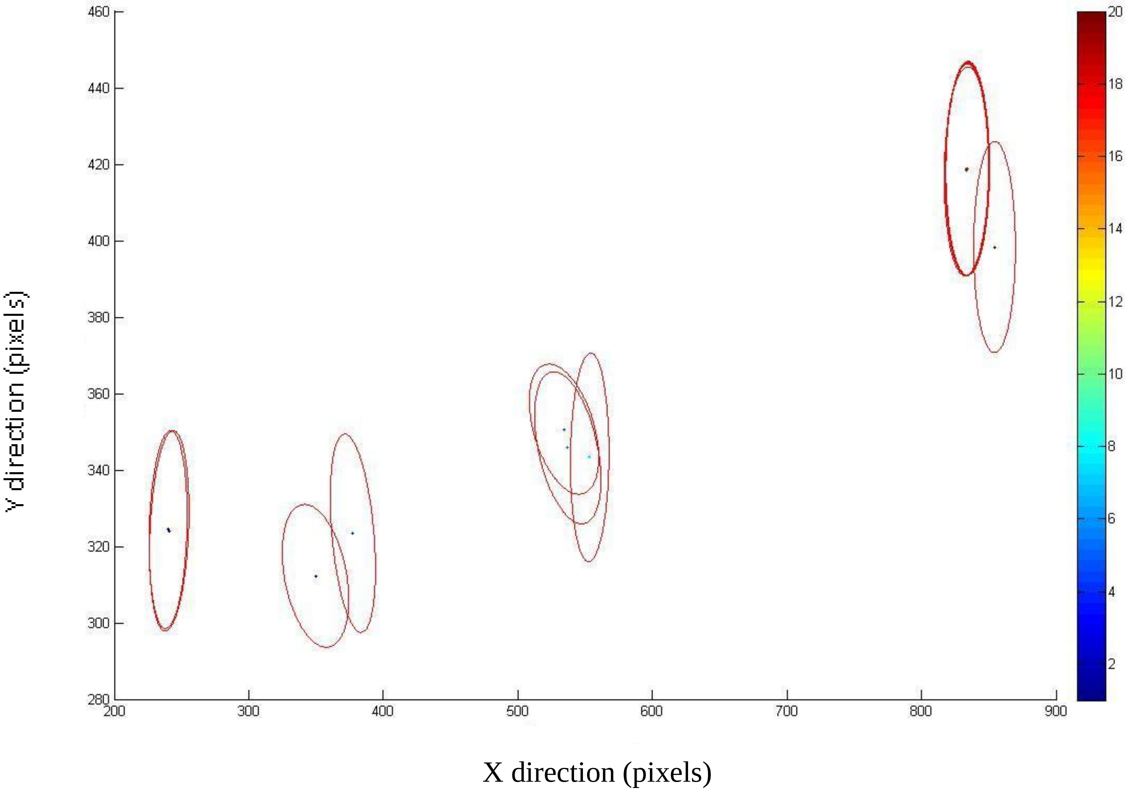

Figure 5. Particle position and orientation (showing time on colourbar)

4 DISCUSSION

This method presents an alternative approach for conducting a relatively well practised experimental technique. Observation of river beds is an old technique, however when applying photogrammetry to the analysis process, new insights may be revealed.

The use of painted natural gravel particles required a fairly labour intensive set up for the experiments. The potential for the particles to stick to one another meant hand spraying was required, and to ensure complete coverage was achieved. In addition, manual inspection of most grains was required to ensure individual coverage. With a large quantity of grains, this proved to be time consuming.

The time consuming set up phase of these experiments can be viewed as worthwhile investments, providing the capacity for quick comprehensive analysis of large quantities of data in future experiments. Once developed, the program based on the Matlab code may be used an infinite number of times for quick analysis, and may also be altered for use in related or more advanced purposes. Subtle attributes may be observed, such as the orientation or movement of single or numerous particles which will aid investigation into sedimentary processes.

5 SUMMARY AND CONCLUSIONS

Experiments were conducted into sedimentary processes with the aim of using photogrammetry to assist analysis. Initial investigations have used photogrammetry to observe the surface grain size on a test section over time. The presented analytical process contained the following four steps: Identify ROI, determine threshold values for coloured particles, isolate the particles and then calculate the area coverage and plot the percentage for each colour with time.

A particle tracking algorithm has been developed, where a target particle is identified and the number of pixels in the particle is counted. The position of the target particle in subsequent images is determined by identifying the particle with the closest number of pixels matching the original target particle, within a reasonable displacement range of the target particle. With the inclusion of image subtraction to eliminate all stationary particles, the algorithm could successfully track a particle over an extended duration.

This new technique of analysis is a versatile and efficient method for research into sedimentary processes.

6 ACKNOWLEDGEMENT

The authors would like to acknowledge the excellent assistance and expertise of the lab technicians Geoff Kirby and Jim Luo.

REFERENCES:

Black, K. S., Athey, S., Wilson, P., and Evans, D. (2007). "The use of particle tracking in sediment transport studies: A review." In: *Geological Society Special Publication*, P. S. Balson and M. B. Collins, eds., 73-91.

Chin, C. O. (1985). "Stream Bed Armouring," University of Auckland, Auckland.

Keshavarzy, A., and Ball, J. E. (1999). "Application of image processing in the study of sediment motion." *Journal of Hydraulic Research/De Recherches Hydrauliques*, 37(4), 559-576.

Lane, S. N., Chandler, J. H., and Porfiri, K. (2001). "Monitoring river channel and flume surfaces with digital photogrammetry." *Journal of Hydraulic Engineering*, 127(10), 871-877.

Li, R., Li, H., Zou, W., Smith, R. G., and Curran, T. A. (1997). "Quantitative photogrammetric analysis of digital underwater video imagery." *IEEE Journal of Oceanic Engineering*, 22(2), 364-375.

McEwan, I. K., Sheen, T. M., Cunningham, G. J., and Allen, A. R. (2000). "Estimating the size composition of sediment surfaces through image analysis." *Proceedings of the Institution of Civil Engineers: Water, Maritime and Energy*, 142(4), 189-195.

Moore, E. J. (1976). "Underwater Photogrammetry." *The Photogrammetric Record*, 8(48), 748-763.

Schuyler, A., and Papanicolaou, A. N. (2000). "Image analysis technique to track the evolution of sediment clusters." *Experimental Techniques*, 24(5), 31-34.

Wang, Y., Wang, D., Wang, L., and Zhang, Y. (2009). "Measurement of sand creep on a flat sand bed using a high-speed digital camera." *Sedimentology*, (Available Online).