Mathematical and Computational Applications, Vol. 15, No. 3, pp. 420-427, 2010.

APPLICATION OF IMAGE PROCESSING IN UNSTEADY FLOWS TO INVESTIGATE BED LOAD TRANSPORT

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Abstract- Image processing is a promising technique to investigate bed load characteristics and its movement which has been applied in steady flow conditions for the last few decades. In this study, it is aimed to perform experiments in unsteady flows through generating a hydrograph to apply this technique and calculate the bed load transport. The sediment motion is recorded by a video recorder. The video records are analyzed by image processing techniques to determine the number and area of active grains moving at any instant as well as the average velocity of the grains. A bed load transport formula is introduced particularly used by the digital video analysis in which the time variation of the bed load due to the hydrograph could be precisely determined. It is revealed that the bed load determined at two sections of the flume is in accord and the bed load – time curve has a fluctuating character.

Keywords- Image Processing, Bed Load Transport, Unsteady Flow

1. INTRODUCTION

In open channels with mobile bed, there is a continuous interaction between flowing water and sediment particles. Different kinds of instruments for bed load measurement have been developed such as pressure-difference type and basket-type bed load sampler [1]. Application of image processing technique is a new and promising technique to investigate the sediment characteristics and its movement since it is a non-intrusive measuring technique [2]. Fraccarollo and Marion [3] and McEwan *et al.* [4] applied image processing in order to extract information on the granulometric properties of still grains [5]. Graham *et al.* [6] determined the grain size distribution of the bed material from the digital images by using various algorithms of image processing. Keshavarzy and Ball [7] used the image processing technique to record sediment particle motion and apply a cross correlation to find a relation between the number of sediment entrained and turbulence. Papanicolaou *et al.* [8] applied image processing technique to provide quantitative information about the frequency of the entrainment of the painted glass beads, their displacement distance and the mode of their motion in conjunction with laser doppler velocimeter measurements of the fluid velocity. Strom and Papanicolaou [9] used digital images in order to characterize the sediment clusters formed at the river bottom morphologically in terms of their shape, geometric properties and their spatial arrangement. Radice *et al.* [10] introduced the concept of the aerial concentration of the sediment in motion and described how the aerial concentration of transported particles can be measured by subtracting successive frames of digital video of sediment motion. By identifying the number of displaced grains from the resulting subtracted image, it is possible to determine the number of particles in motion for each frame [2]. Only the number of grains determined form the image processing is used in calculation of aerial concentration.

In this paper, not only the number of grains but also the average velocity of the sediments is obtained from video records are used in order to calculate the bed load. This is the first time that the image processing technique is applied in unsteady flow conditions by generating a triangular hydrograph. The results presented in this paper correspond to those obtained from the hydrograph with rising and falling durations of 15 seconds, from the base value of 12.0 l/sec to the peak value of 53.5 l/sec without sediment feeding.

2. EXPERIMENTAL SET-UP AND INSTRUMENTATION

Experimental studies are performed on an experimental system which has been constituted from a rectangular flume of 80 cm in width and 18.6 m in length. The transparent sides of the flume are 75 cm high and made from acrylic. The input hydrograph is generated by a pump with regulated rotational speed. The general view of the system is given in Figure 1.a. The thickness of the mobile bed is 8 cm along the flume. Bed material used in the flume is composed of uniform graded material with the diameter, D_{50} of 4.8 mm. The geometric standard deviation, σ_g is 1.4 mm.

Before the experiments, the flume bed is mixed to achieve homogeneity through the vertical and stream-wise direction and the bed slope is fixed to 0.005. The flow rate at the beginning is slowly increased to the base value which is below the sediment inception threshold conditions in order not to disturb the sediments.
The bed-load transport is recorded by a 640x480 pixel 25 fps SONY CCD video recorder located at 11 m and 16 m from the flume entrance mounted vertically oriented to the bed (Figure 1.b). An acrylic plate is used to prevent disturbance of the wavy surface. While the flow depth increasing, this transparent acrylic plate was raised over the water surface keeping it in contact with the water surface, and then lowered in accord with the decrease in flow depth.

Figure 1. (a) The general view of the flume, **(b)** configuration of the video recorder and acrylic plate

3. COMPUTATIONAL METHOD OF BED LOAD AND RESULTS

A video recorder located at x=11m and x=16 m is used to visualize and calculate the amount of the sediment in motion by image processing technique. The frames in which the sediment is moving is taken into consideration. Totally there exist 600 frames and 631 frames which have a total duration of approximately 25 seconds.

In order to determine the motion of sediments, one should define the subsequent frame numbers. 1 to 5 frames are studied. It is observed that the most moving sediments are rolling and saltating. Therefore the area of the sediment changes frame to frame and it is difficult to capture the sediment in two frames having more than 2 frame intervals. Therefore 1 frame interval is selected for the investigation.

In the image processing part of the study, the average velocity of the grains in two consecutive frames is obtained. The pixel values of the two subsequent images of grayscale (Figure 2.a and 2.b) are subtracted and two images are obtained. The initial and final positions of the sediments are obtained as shown in Figure 2.c and Figure 2.d. For x=11m 2x25 and for x=16m 2x60 frames are manually examined at various times. It is observed that some of the sediments are just fluctuating and do not move afterwards. Also because of the variable lightening conditions some shades appear which result in white areas in binary image although there is no movement. This introduces noise and requires careful detection of the sediments. Therefore, for each consecutive frame, a variable threshold value is used to convert the gray scale image into the binary image. A median filter in Matlab is used to eliminate the noise from the binary images [11]. The final binary images are given in Figure 2.e and 2.f. The small white areas in the binary image allow us to determine the extent of the movement as well as the velocity of sediments. Then the average velocity of the sediments is calculated by knowing the horizontal and vertical displacement and the time interval as given in Figure 3.a and Figure 3.b.

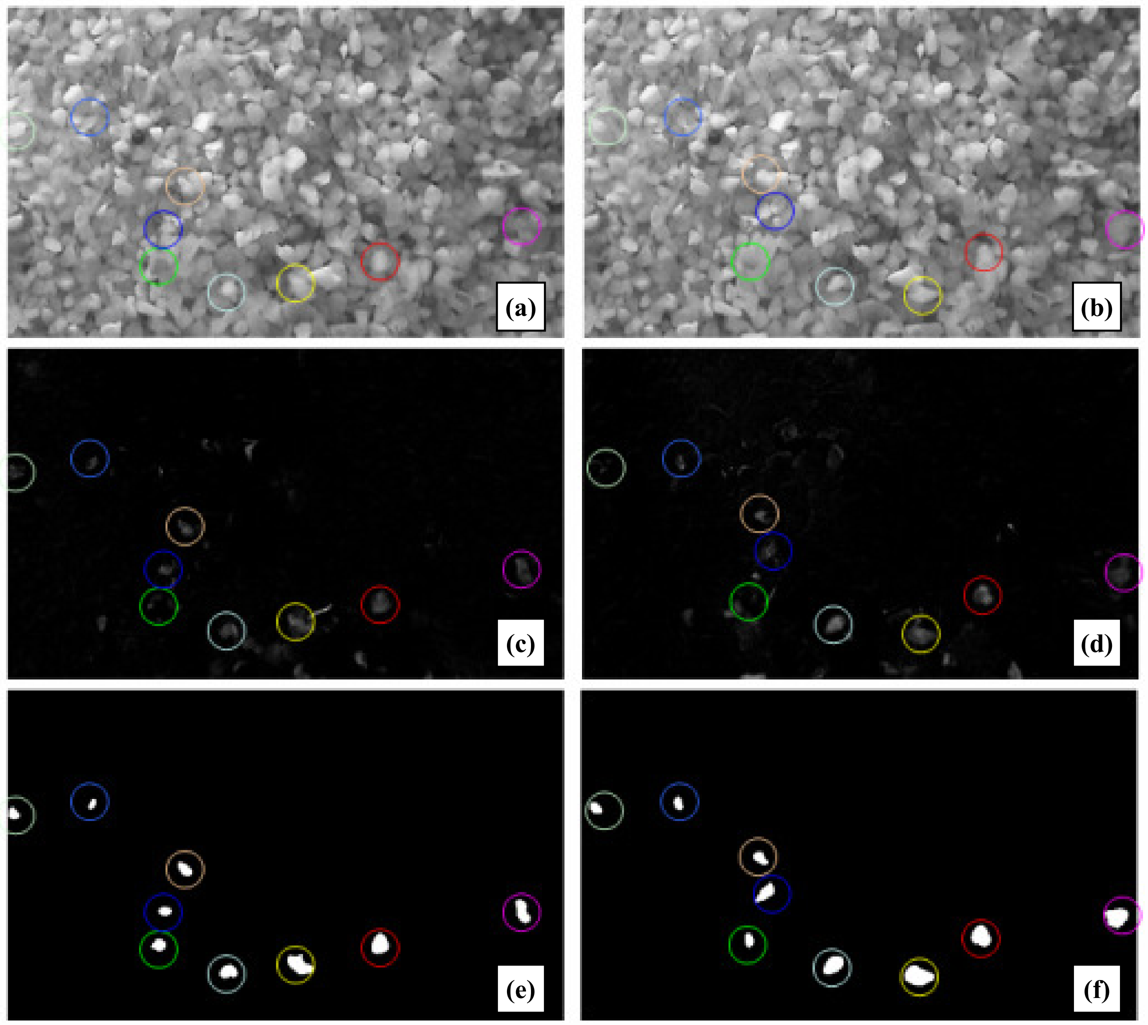

Figure 2.a,b,c,d Movement of sediment and its processing procedure frame 100 (t=21.8 sec) at x=16m

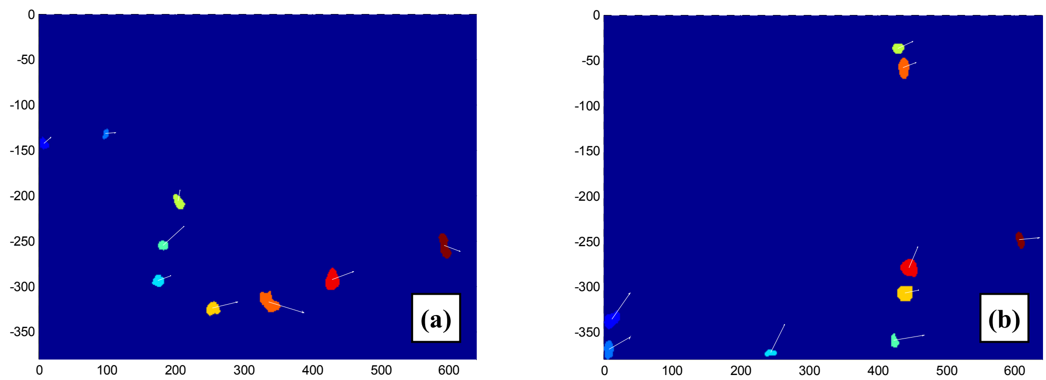

Figure 3. Sediment velocities in two consecutive frames, **(a)** at t=10 sec (frame 60), **(b)** at t=26 sec (frame 200) at x= 16m.

In order to obtain the individual grain velocity, 39 grains at various frames are tracked and their instantaneous velocities are determined and compared with the velocities averaged by frame as given in Figure 4. It is seen that the frame velocity is nearly constant and equal to the average value of 17.8 cm/sec at x=16 meters throughout the hydrograph, whereas the individual velocities fluctuate around this value. It is revealed that the two ways of velocity determination is in accord. At x=11m the average frame velocity is 15.8 cm/sec. For the proceeding calculations, the average frame velocity is considered.

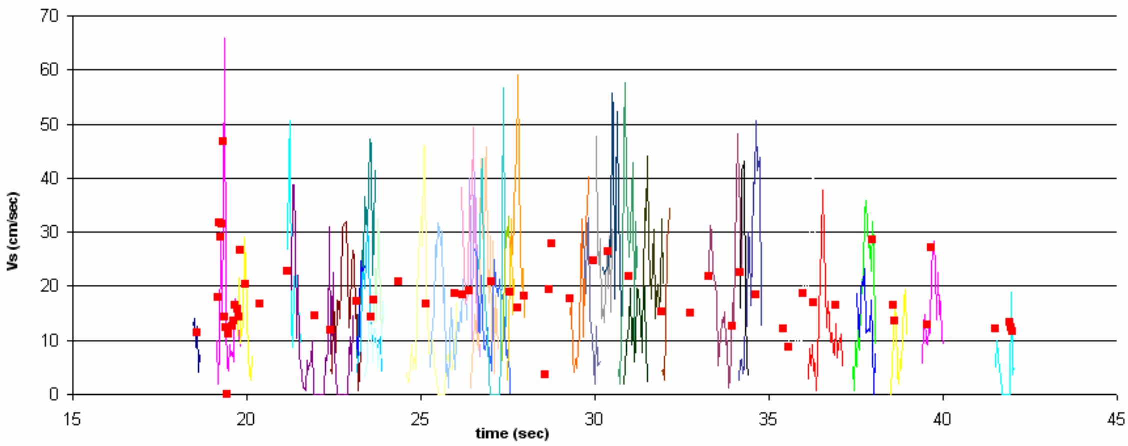

Figure 4. Time variation of the sediment velocities averaged by frame and instantaneous individual sediment velocities at x=16m

The records are analyzed to determine the number and area of active grains moving at any instant. In literature it is advised to make a manual calibration for the determination of the moving area and the total number of active sediments moving at any instant [2]. A constant threshold of 0.130 and filter of 8 are used for area which makes the best fit as given in Figure 5.a and a constant threshold of 0.190 and filter of 8 are used for number of grains which makes the best fit as given in Figure 5.b for the recordings at x=16m. At x=11m, the values are 0.072 and filter of 8 is used for area and a constant threshold of 0.107 and filter of 8 is used for number of grains. The noise is due to the shades and fluctuating sediments results deviation for both number of grains and the area. The sediments are rolling, sliding and saltating through the observation period. Therefore the area of the specific sediment in one frame may not be the same shape and size at the proceeding frame.

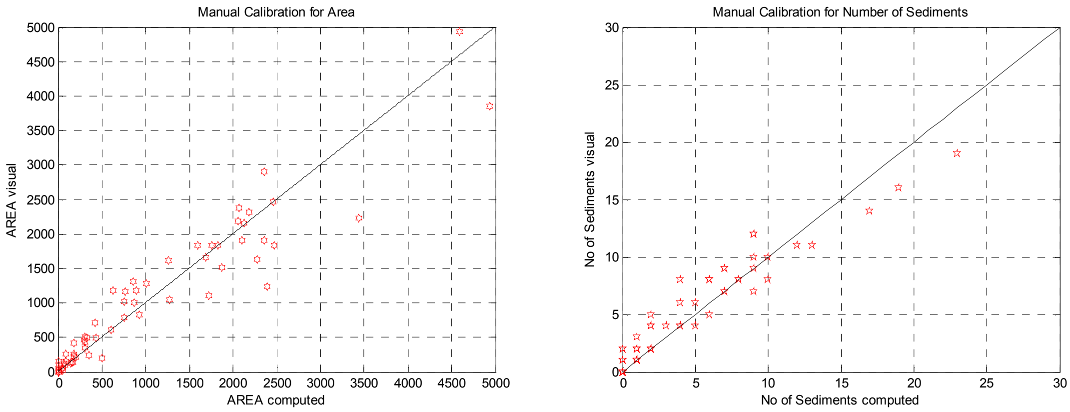

Figure 5. Calibrated results for **(a)** moving area in pixel^2, **(b)** number of grains at x=16m

The area in pixel^2 is converted into cm^2 by knowing the frame limits i.e. aspect ratio in pixels and cm which was previously determined by a ruler. The average diameter of the moving sediments is determined by using the following equation,

$$D=\sqrt{\frac{4}{\pi}\frac{A}{N}} \tag{1}$$

where A is the area of active grains in cm^2, N is the number of active grains and D is the average moving sediment diameter in cm. The time variation of the diameter of the moving sediment is given in Figure 6. It is revealed that the average diameter of the moving sediment fluctuates around D_{50} of the bed material.

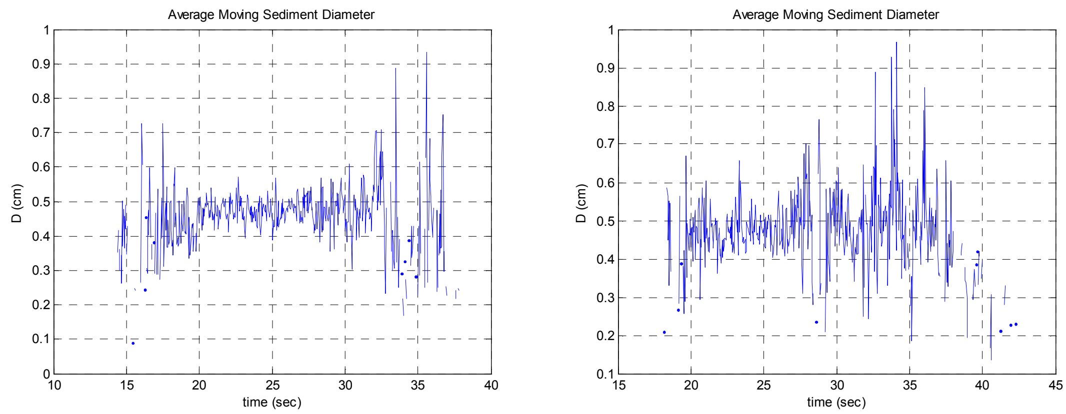

Figure 6. Time variation of average moving sediment diameter **(a)** at x=11m**, (b)** at x=16m

The average velocity of the moving sediments in a frame, the diameter and number of active sediments at each frame is used to find the bed load per unit width by using the following equation.

$$g_{bA}=N\left(\frac{\pi}{6}D^3\right)\gamma_S\,\frac{1}{\Delta x\Delta y}V_s \tag{2}$$

where g_{bA} is the bed load calculated from the image processing technique, D is the diameter of active grains, V_s is the average velocity at each consecutive frame, Δx and Δy are the horizontal and vertical length reaches of the frame.

The bed load per unit width obtained at x=11 m and x=16 m are given in Figure 7 which are in accord. The time at which the motion starts is 14.0 sec and the time at which the motion terminates is 37.2 sec, at x=11m. The time at which the motion starts is 17.8 sec and the time at which the motion terminates is 43.0 sec, at x=16m. The pulsing nature of the continuous bed load transport is obviously seen in this figure where the pulse interval is approximately 3 seconds. Revealing this fluctuation is another advantage of image processing technique in the determination of bed load measurement. It should be noted that, the t=0 sec is the hydrograph generated at the pump. The bed load motion is delayed in the flume.

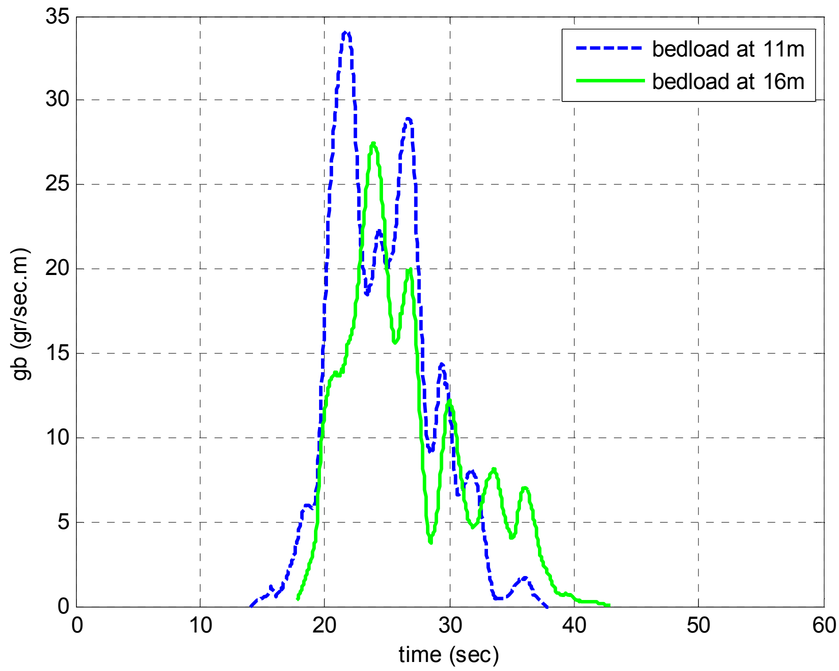

Figure 7. The bed load obtained by the image processing technique at x=11m and x=16m

4. CONCLUSION

Image processing has a wide application area in hydromechanics especially in the determination of sediment grain size distribution and detection of the sediment movement. In this study, this technique is demonstrated in unsteady flow conditions by generating a triangular hydrograph with rising and falling durations of 15 seconds, from the base value of 12.0 l/sec to the peak value of 53.5 l/sec. The sediment motion is recorded at two sections of the flume, namely 11 m and 16 m. The records are analyzed by image processing techniques to determine the number and area of active grains moving at any instant. The average velocity of the grains in two consecutive frames is obtained. Also some grains which are moving are tracked and their instantaneous velocities are determined. Although the individual sediment velocities fluctuate considerably, the average velocity of frames revealed that as soon as the sediment incept their motion, the velocity of them is kept nearly constant till nearly the end of the hydrograph. It is revealed that the average diameter of the moving sediment fluctuates around the D_{50} of the bed material. The number of grains and the average velocity of the sediments are used in order to calculate the bed load. It is observed that the bed load motion is not continuous, but sporadic, which results in fluctuating character. The time variation at two sections in the flume is in accord.

A**cknowledgement**-The authors thank also TÜBİTAK (project number 106M274) for its financial support. This study is a part of a PhD thesis of the first author done in The Graduate School of Natural and Applied Sciences in Dokuz Eylül University.

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