DSM MEASUREMENT FOR EXPOSED GRAVEL SURFACE USING CLOSE-RANGE PHOTOGRAMMETRY WITH MULTI-SCALE IMAGES

Jui-Teng Tsung[1] and Chi-Kuei Wang[2]
[1]Graduate student, Department of Geomatics, National Cheng Kung University,
No.1, University Road, Tainan City 701, Taiwan; Tel: + 886-6-2370876#809;
E-mail: return1225@hotmail.com

[2]Professor, Department of Geomatics, National Central University,
No.1, University Road, Tainan City 701, Taiwan; Tel: + 886-6-2370876#825;
E-mail: chikuei@mail.ncku.edu.tw

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ABSTRACT: Measuring the exposed gravel surface geometry is important for understanding the flow characteristic. This research has developed a reliable and precision methodology to generate the Digital Surface Model (DSM) of gravel surfaces using multi-scale images from close-range photogrammetry. The camera was calibrated on-site corresponding to different scale images with a self-calibration bundle adjustment using coded retro-reflective targets and the DSM of the gravel surface was reconstructed for two scales from different scale images relatively. The small scale DSM was used as the control surface covering entire area (4.5 m × 4.5 m). The large scale DSMs contain more detailed elevation variation covering the diagonals (6 m × 1 m) of entire area and are registered to the small scale DSM by iterative closest point (ICP). Three fields with a size of 4.5 m × 4.5 m have been tested and discussed, and the results are provided and validated with high accuracy total station. The ortho-images can be generated and apply for determination of grain size distribution.

1. INTRODUCTION

The surface variation of gravel surfaces is a result of river flow work. Measuring the surface geometry is important for understanding the flow characteristic, such as the grain- and form-scale roughness derived from the surface elevation using a variogram of the surface elevation (Robert, 1988).

The elevation information of gravel surface was firstly acquired by using manual profiler for the length of 30 cm to 6 m at varying intervals (Robert, 1988; De Jong, 1992; Nikora, Goring et al., 1998). The manual profiler, usually consisting of a perforated box and several long sticks, is easy to build and requires minimal training. A long profiler would be needed if the gravel surface under study has large spatial extent. Thus, its bulkiness becomes the main concern for transporting this instrument for remote river sites.

The operation and post-processing of terrestrial laser scanner (TLS) is rather straightforward and start to gain popularity in the Surveying, Hydrology, and Geomorphology communities. However, due to the shear price of TLS system (usually at the range of 100 to 200 thousand USD) and the relatively heavy weight of the TLS system and its accessories (usually 10 to 50 kg in total), the practical use of TLS become limited to the study reaches that have easy access, but not of the most significant scientific importance. Recent development of TLS has been able to produce a TLS of 5 kg. However, its durability (mainly the mechanical parts) in the harsh field environment (direct sun light, heat, humidity, etc.) needs to be confirmed before being used as an operational instrument.

Two-dimensional (2-D) elevation information with the spatial extent of 1.8 m × 1.6 m (Butler, Lane et al., 1998) and 3.7 m × 14.4 m (Gessesse, Fuchs et al., 2010) of gravel surface has also been acquired by photogrammetry. The 2-D information such as Digital Surface Model (DSM) is useful for determining the directional variation. However, the setup of the ground control points (GCPs) requires other instruments, such as a total station and its accessories, all of which would increase the amount of instrument that needed to be transported in the field. In addition, the post-processing of photogrammetry requires specialized personnel. Recent advancements of close-range photogrammetry, including fully automatic camera self-calibration bundle adjustment and multi-image matching, have eased the post-processing burdens and made close-range photogrammetry available to a broader scientific community (Remondino, Rizzi et al., 2010). The former technique enables the determination of the interior orientation (IO) parameters of the lens of the commercial grade digital SLR camera and the exterior orientations (EO) parameters of each photograph taken by that camera with accessories coded targets. The latter technique can then reconstruct the 3-D digital model of the object of interest using the IO and EO parameters determined by the former technique with high accuracy, benefitted from the redundant information of the multiple photographs. In addition, the price and weight of digital SLR camera are decreasing in recent years. These have made it a potentially useful tool for remote fields.

In this research, a method has been developed to acquire the elevation information of exposed riverine gravel bed with minimum equipment in order to maximize its portability to remote sites based on two different scale photographs. The small scale photographs are used to produce a DSM as a control base. Multiple highly detailed DSMs are created (in order to cover a large spatial extent) from the large scale photographs and are registered to the small scale DSM using iterative closest point (ICP). Three test sites were chosen at Hou-Jue River of southern Taiwan. The elevation accuracy obtained by our method is validated by a total station of 1 mm accuracy with the root mean square error (RMSE) of 2.9 – 4.3 mm.

2. MATERIAL AND METHOD

2.1 Study Area

The streamwise and transverse directions are the two directions of concern in the study. Because the elevation information collected in the study will be further used for roughness calculation, which required a length of 6 m, the field setup was complied with that requirement.

The field data collection was carried out for three exposed gravel surfaces (denoted as site 1 – 3 in Figure 1) with a size of 4.5 m × 4.5 m (the diagonals of each site are 6 m in length and are aligned to the streamwise and transverse directions determined in the field) at Hou-Jue River, Tainan, Taiwan in June 2011 after the monsoon season (from April to May). The three study sites have different surface roughness characteristics with the D_{90} value of site 1to 3 being 25.5, 57.5 mm and the more, respectively.

2.2 Data Acquisition Procedure

In a normal photogrammetry procedure, the EO parameters of each photograph are determined by the aerial triangulation with GCPs. The setup of GCP requires other assisting instruments, such as GPS or total station, each of which adds more weights to field instruments and poses as burdens to field operation. The goal of this research is to develop a method to acquire the elevation information of the gravel surface in a riverine environment with minimum equipment, so the use of a GPS and total station was avoided.

A consumer-grade camera, Nikon D200 with an AF-S NIKKOR 20 mm lens was employed to acquire images of 3872 pixel × 2592 pixel in this research. The camera was calibrated on-site using color coded retro-reflective targets to determine the IO parameters of the camera lens by iWitnessPro (Photometrix), including the focal length (c), principle points location (x_0, y_0), and additional parameters (k1 – k3) (Cronk, Fraser et al., 2006).

In addition, we propose a new method for determining the EO parameters by two steps. In the first step, a coarse DSM (referred as small scale DSM hereafter) for the 4.5 m × 4.5 m area, used as a control surface, was obtained from a set of small scale images (see Section 2.4 for details). A detailed DSM (referred as large scale DSM hereafter) of 1.8 m × 1 m in size was obtained from another set of large scale images (see Section 2.5 for details). In order to cover a length of 6 m with 50% overlap, 7 large scale DSMs are needed for each diagonals. Thus, a total of 14 DSMs were obtained. In the second step, each of the large scale DSMs were registered to the small scale DSM based on the common geometric features both presented in the small scale and large scale DSMs by using ICP. A combined large scale DSM covering the two diagonals of a 4.5 m × 4.5 m area was then generated from the interpolation of the 14 large scale DSMs.

For each set of large scale images, the EO parameters were calculated independently in local coordinate systems. In addition, a rotation matrix, which transformed the large scale DSMs to the small scale DSM, of each large scale DSM was also acquired as a result of ICP. Because the large scale DSMs and its corresponding set of large scale images are in the same local coordination system, applying the rotation matrix to the EO parameters of each set of large scale images would make them into a global coordinate system (of the small scale DSM). The global coordinate system was defined by assigning the origin and x- and y-axis directions using three of the coded targets, respectively. After transforming all the 14 sets of EO parameters of the large scale images into the same global coordinate system, an ortho-image was then generated from them with the combined large scale DSM.

2.3 Validation Check Points

A high accuracy total station (Trimble 601MR), with 1 mm + 1 ppm distance precision and 1″ angular accuracy, accompanying with a mini prism, was employed for the assessment of the DSM accuracy. A total of 125 – 130 check points were collected for each site. And, 20 of them (16 were distributed equally in the 4 large scale DSMs at the four ends of the diagonals and 4 were in the central large scale DSM) were also measured in the iWitnessPro in order to transform the check points to the global coordinate system of the small scale DSM. The accuracy of the DSM was assessed by comparing the elevation difference between the check point and combined large scale DSM, and this difference was quantified as RMSE.

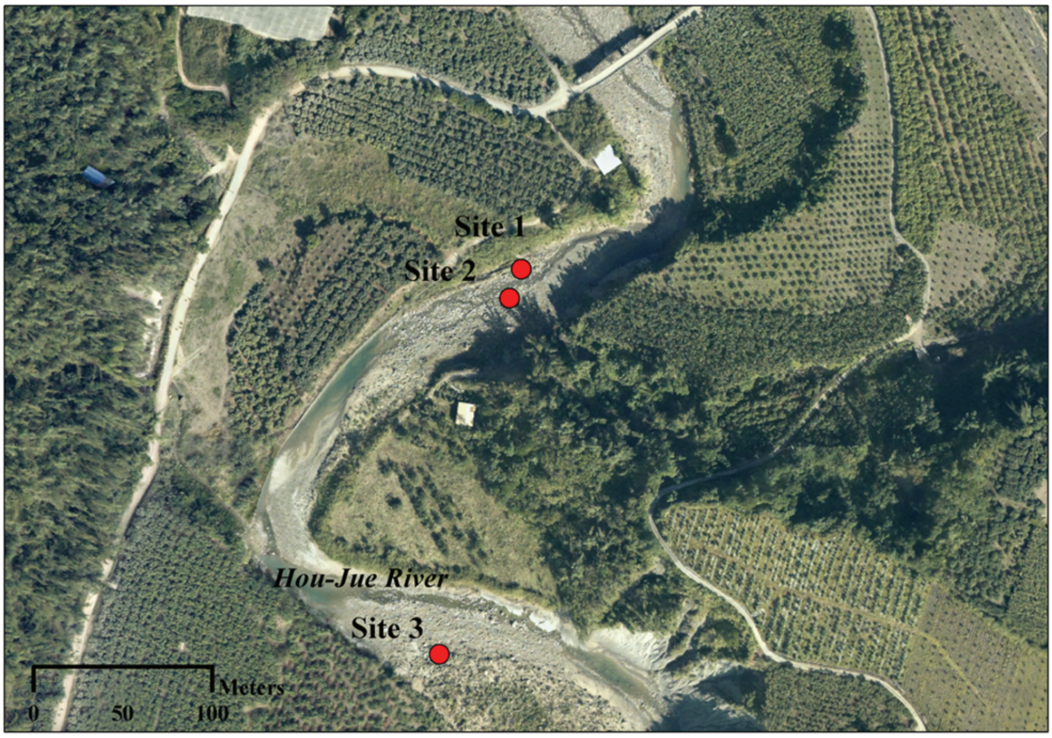

Figure 1 The three study sites at Hou-Jue River.

2.4 Small Scale Images and DSM

In order to acquire the whole 4.5 m × 4.5 m area, the SLR camera was elevated at an altitude of 3 m above the gravel surface with the help of a telescoping pole and an external apparatus (Zigview S2). A total of 20 large-sized (30 cm × 21 cm) coded targets, which can be recognized in small scale images, were placed evenly around the perimeter of the 4.5 m × 4.5 m area. And, additional 4 large-sized targets were placed close to the central area within each site. Figure 2a shows an example for site 1.

As a consideration for DSM generation using CLOROMA (4DiXplorer), the images were taken revolve around the site from a titled perspective and the orientation between two consecutive images needed to be less than 20 degrees. Thus, a minimum number of 24 small scale images were necessary for the generation of small scale DSM for each site. The whole set of small scale image were used in the self-calibration bundle adjustment to determine the IO parameters of the camera lens and EO parameters of each image simultaneously in iWitnessPro.

Each set of small scale images were further brought into CLOROMA, which employs a multi-image matching algorithm (Remondino, El-Hakim et al., 2008), with associated IO and EO parameters to generate the small scale DSM. Figure 2b shows the small scale DSM, with a grid size of 3 mm, for site 1. The black/yellow textured boards, which were used to ensure consistent geometric features in both scale DSMs, shown in the small scale image (Figure 2a) are clearly identified as flat surfaces in the small scale DSM (Figure 2b).

2.5 Large Scale Images and DSM

In order to acquire the large scale images, the focal length of the SLR camera was adjusted to adapt for the camera altitude of 1.5 m. A new set of IO parameters were then needed. For highly accurate large scale DSM, the IO was determined first in iWitnessPro using a calibration setup with 30 coded retro-reflective targets and 18 images. These coded targets needed to be randomly distributed with varying elevation and to fill each of the images. It is preferred to have high convergent angle between each images with different rotation.

For large scale DSM acquisition, a total of 16 small-sized targets, which can be recognized in large scale images, were placed at the perimeters for each of the 1.8 m × 1 m area and the 4 black/yellow textured boards were placed inside the rectangular area but not to block the diagonals of the 4.5 m × 4.5 m area. A total of 28 texture boards were used in this study (see the field arrangement in Figure 2a). Figure 2c shows the field setup for site 1. Coincidentally, the large scale images consist of a total of 16 images, which can be divided into three rows (referred as top, left, and right rows). There were 6 convergent images in the top row and 5 ones for more convergent in the left and right rows, respectively. The EO parameters for each set of 16 large scale images were calculated independently using the corresponding IO parameters which determined from the camera self-calibration procedure and the DSM generation was followed by that of small scale images. Figure 2d shows a large scale DSM of a grid

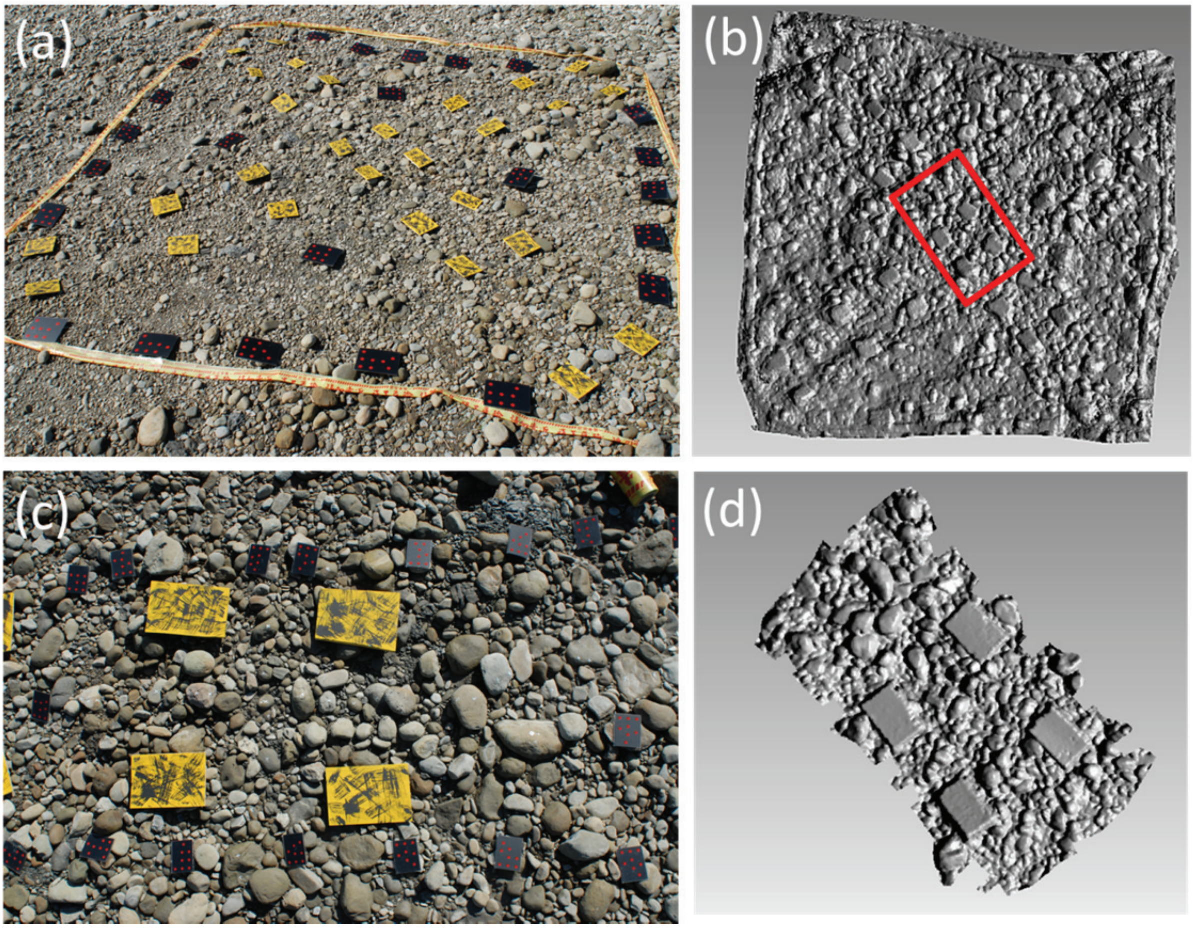

Figure 2 The images and DSMs for site 1. (a) A small scale image taken at an altitude of 3 m. (b) The small scale DSM. (c) A large scale image taken at an altitude of 1.5 m of a nadir perspective. (d) A large scale DSM corresponds to the rectangular area in (b). The four flat surfaces shown in the rectangular area in (b) and in (d) are the same black/yellow textured boards (which also can be seen in (a) and (c)). Notice that there are more elevation details in (d) than (b).

size of 3 mm, which corresponding extent is indicated in Figure 2b as a rectangle in site 1. The black/yellow textured boards shown in the large scale image (Figure 2c) are clearly identified as flat surfaces in the large scale DSM (Figure 2d) as well.

2.6 Combination of DSMs from Two Scales

Each of the DSMs, both large and small scales, is of independent coordinate system. The registration of the 15 DSMs (1 small scale DSM and 14 large scale DSMs) is facilitated by the black/yellow textured boards as the control surfaces (Figure 2) using ICP by Geomagic (Geomagic) software. The flat surfaces of the textured boards were regarded as the control surfaces in the case where common geometric features of the gravel surfaces were difficult to find in both scale DSMs.
To start, the initial registration was conducted successively for each of the large scale DSMs by manual selection of the corresponding surface features in the large and small scale DSMs. Then, the fine tuning procedure would minimize the deviation between each of the large scale DSMs and small scale DSM and between overlapping large scale DSMs. The small scale DSM was fixed during ICP.

3 Results

3.1 DSM Results

Figure 3a – 3c show the DSM results of the diagonals of the 4.5 m × 4.5 m area in site 1 – 3. The black/yellow textured boards are clearly visible in Figure 3a as two rows of flat surfaces along the two diagonals. As the size of the gravels become larger in site 2 and 3, these flat surfaces become less distinguishable (cf. Figure 3b and 3c).

Table 1 Assessment of DSM result.

Study Area	Number of Check Points	RMSE (std. dev.)
Site1	105	2.9 mm
Site2	110	4.3 mm
Site3	109	3.6 mm

Table 2 The gravel sizes for site 1and site 2.

	Site 1		Site 2	
	Streamwise	Transverse	Streamwise	Transverse
D_{50}	8.8	10.9	8.2	12.3
D_{90}	23.5	28.8	52.7	65.6

(mm)

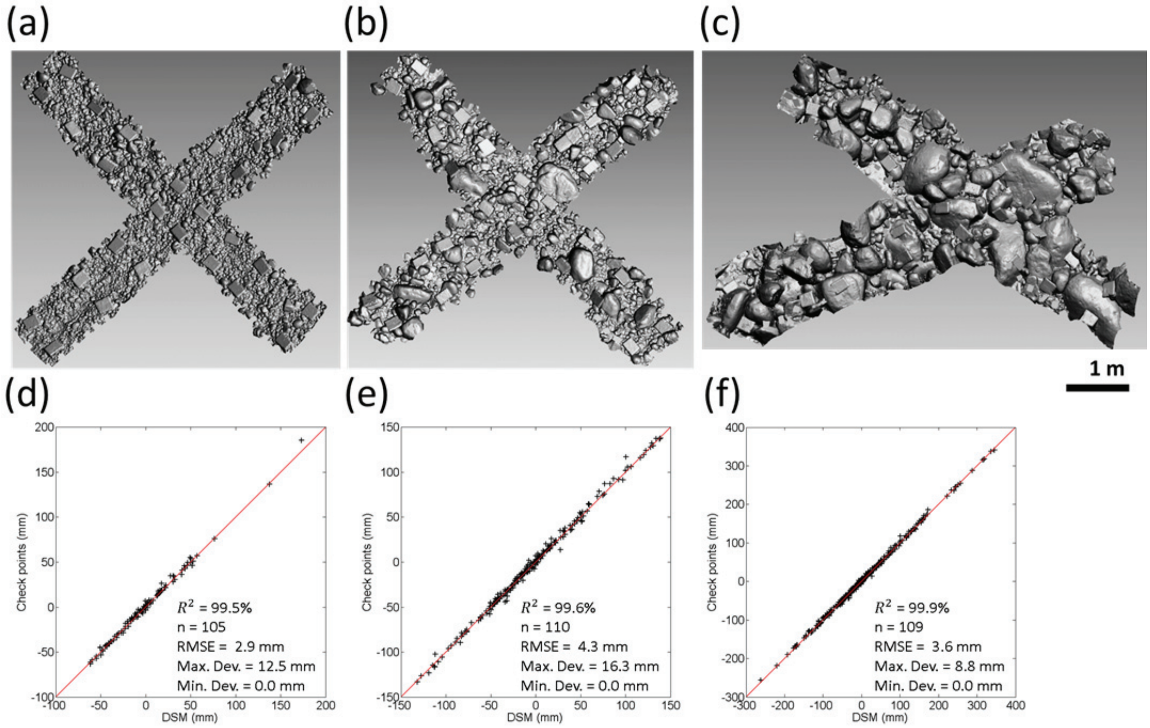

Figure 3 The DSM results of (a) site 1, (b) site 2, and (c) site 3 and the accuracy assessment of the DSM for (d) site 1, (e) site 2, and (f) site 3

Notice that the two diagonals in site 3 are not orthogonal due to the presence of fractured gravels, which pose as obstacles for check point measurement using a mini prism.
The DSM agrees very well with the check point as the RMSE shown in Table 1 being 2.9, 4.3, and 3.6 mm and the coefficient of determination R^2 shown in Figure 3d – 3f being 99.5%, 99.6%, and 99.9% for site 1 – 3, respectively. They are all centered around the one to one line as the scatter plot shown with the maximum deviation being 12.5, 16.3, and 8.8 mm and the minimum deviation being 0 mm for site 1 – 3, respectively.

3.2 Ortho-images and Grain Size Distribution

The ortho-images of site 1 and 2, which generated by LPS (ERDAS Inc.), are shown in Figure 4a and 4b. The significant elevation variation of site 3 precludes the generation of a visually pleasing ortho-image, and thus, it is not shown here. The best fit elliptic for the gravels that resided on the diagonals of the 4.5 m × 4.5 m area were determined from the manual digitization of those gravels by ArcGIS (ESRI), and are shown in Figure 4a and 4b as overlay on the ortho-image. The b-axes obtained from the best fit elliptic were summarized as the gravel size distribution for the streamwise and transverse diagonals for site 1 and 2 shown in Figure 4c and 4d and the characteristic gravel size D_{50} and D_{90} were shown in Table 2.

4 CONCLUSIONS

A new method of using close-range photogrammetry to reconstruct a highly detailed DSM of gravel surface with large spatial extent (4.5 m × 4.5 m) has developed in this research. It has a great potential to be used in remote river reaches because of its light weight and ease of setup.

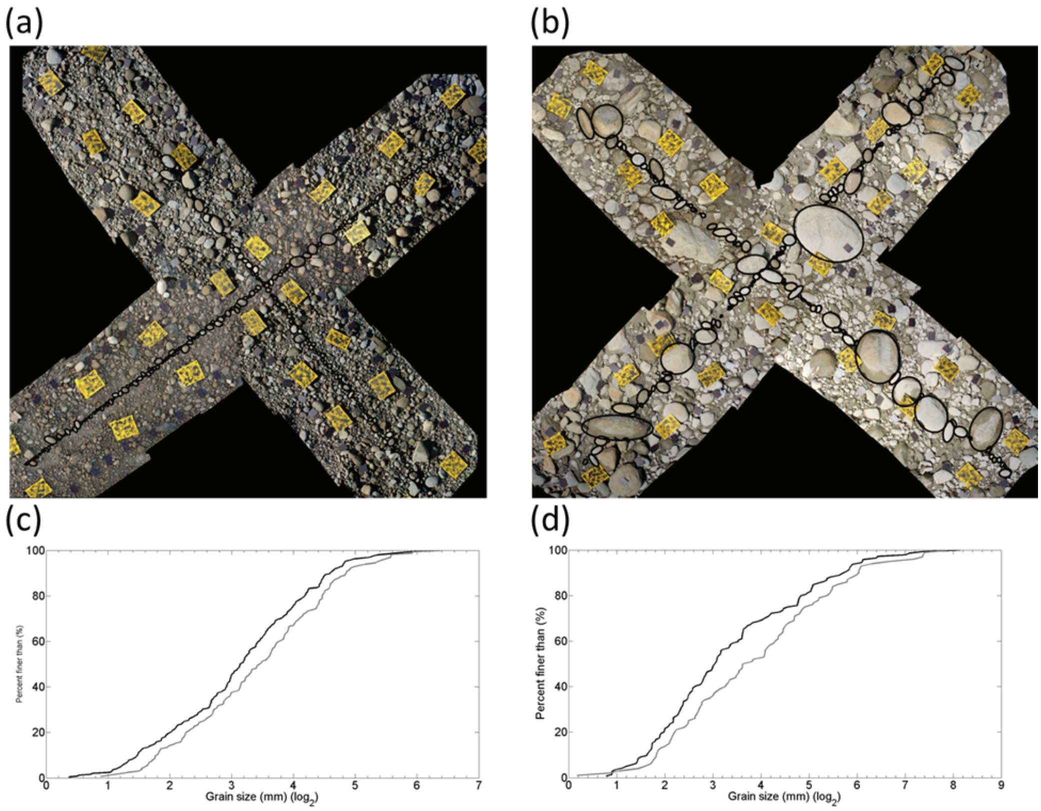

Figure 4 The ortho-image of (a) site 1 and (b) site 2. The best fit elliptic was overlaid on the gravels that reside on the diagonals of the 4.5 m × 4.5 m area. The grain size distributions for the streamwise (black line) and transverse (gray line) diagonals of (c) site 1 and (d) site 2.

The burden of generating DSM is lessened by the highly automated procedures using the commercially available packages, iWitnessPro, CLORAMA, Geomagic, LPS, and ArcGIS for camera calibration, determination of IO/EO parameters of images, generation and registration of DSM, ortho-image generation, and determination of grain size distribution, respectively.

The DSM results of three experimental fields are quite good as the validated accuracy using check points set by high accuracy total station, which is 2.9, 4.3, and 3.6 mm for site 1 to 3, respectively. And, the corresponding ortho-images are used to calculate the grain size distribution of streamwise and transverse diagonal for site 1 and 2. This research shows the advantage of our proposed method which not only can reconstruct the high accuracy DSM of gravel surfaces with large spatial extent but determine the grain size characteristics.

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