Introduction. To investigate the evolution and dynamics of landforms, special for those of riverine or coastal bathymetry, a scale down physical model has been the most reliable scheme. For each tests, the bathymetry needs to be surveyed at least twice: before and after the test. In case the evolution steps have to be recorded, there needs much more bathymetric surveys. The efficiency in topographic survey thus plays an important role in conducting geomorphological experiments. A laboratory bathymetry is usually a 1/100 or even smaller scaled down model to the prototype geometry. Figure 1 shows an example of a bathymetry near a harbor subjected to waves and currents. Precise geometric surveys, special for the vertical coordinate, are of importance as the flow induced bathymetric variation is the key issue to be investigated. Traditional survey methods, which mainly based on single or multiple point acoustic sensors, are able to do the measurement as precise as ±1.0–couple millimeters in the vertical coordinate. The resolution of the horizontal coordinates depends on the density of grids that data was acquired. These traditional methods are apparently time consumed, and it would take much longer time for higher space resolution. Besides, the sensors have to be carried by an X-Y platform that may make other observational errors. Despite the additional time required for draining water, on the other hand, laser scanners and digital photogrammetry were recommended as powerful tools to be applied in surveying a bathymetry exposed to air[1]. Moreover, Westoby et. al. (2012) described the photogrammetry as “a low-cost, effective tool for geoscience applications”[2]. This research therefore focused on the application of photogrammetry in laboratory bathymetry measurement.

Fig. 1. An example of a coastal bathymetry after wave/current action.

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In short, photogrammetry is a technology to measure a surface geometry from photographs. Topographic mapping using aerial photography, which is classified as the “aerial photogrammetry,” may be the most well-known application of photogrammetry with a long history[3]. In contrast to the aerial photogrammetry that normally measures a space of $10^6$ km, the “close range photogrammetry” deals with a space or an object of $10^{-1}$ to $10^1$ m. In aerial photogrammetry the camera is usually mounted with an orientation that is vertical towards the ground to create orthophotos. While in close range photogrammetry the camera is typically hand held or mounted on a tripod. With the advent of high-resolution digital cameras and well-developed software, now the close range photogrammetry has been widely applied in different fields, such as architecture digital models, spatial data collection in a geographic information system (GIS), 3-D manufacturing and even the estimation of the canopy leaf area index in a greenhouse. Unlike these popular applications, the most challenging part for applying the close range photogrammetry to measure a laboratory bathymetry is that there’s almost no clear recognized object in the domain. For example, it is easy to recognize a building or a door or a window from a photo. However, for most laboratory bathymetry, all one can detect is very poor reflection from the sediment or any so-called movable bed material. Nevertheless, some attempts of close range photogrammetry have been made at the morphodynamics of laboratory-scale landscape evolution models[2]. Chandler (1999) demonstrated an approach to generate a digital elevation model (DEM) automatically by using oblique imagery to monitor the evolution of a $0.8 \times 0.4$ m soil surface model placed in an outdoor corn field [4]. Brasington and Smart (2003) investigated the drainage basin evolution in a $2.1 \times 1.0$ m basin by using a photogrammetric data acquisition system. Comparing with a direct observation showed that even they used a moderately cheap software and a relatively low resolution non-metric camera, the photogrammetric results were proved to be sufficient to characterize low relief landforms [5]. Heng et. al. (2010) studied the soil erosion in a $3.9 \times 1.4$ m laboratory basin by close range digital photogrammetry with an oblique convergent configuration. Their results although not as precise as those obtained from a laser scanner, they indicated that the photogrammetric output is able to provide useful topographic information for soil erosion studies. Additionally, the advantages mentioned in this paper of photogrammetry over other surface measurement techniques are the rapid acquisition of data, the relative simplicity and cost effectiveness of the equipment [6].

The objective of this research is to evaluate the performance of the close range photogrammetry applying to the measurement of a scaled down laboratory bathymetry through a case study. A bathymetry of $6.5 \times 8.0$ m in a costal model is to be measured. Effects come from the number of photos and the base height ratio were tested and discussed.

**Experiments.** The bathymetry near a harbor model was the objective area for topographic survey. It's a $6.5 \times 8.0$ m rectangular area, indicated with red line in Fig. 1. To complete a topographic survey via close range photogrammetry, three components are required: a camera, a software and a targeting system that is normally developed as pattern targets to fit the software.

A digital single-lens reflex camera (DSLR) Nikon D5000, of which CMOS sensor: $23.6 \times 15.8$ mm; image size: $4,288 \times 2,848$ pixels, was employed to take the photos. The camera was mounted on a tripod that was transported by a carrier gantry platform (upper right corner in Fig. 1). All the adjustable parts, ex., the focusing ring and the zooming ring, were fixed. The focal ratio (also known as aperture) was set to f/11 to acquire larger depth of field. Among the parameters that may affect the performance of the close range photogrammetry applying to the bathymetric survey, the number of photos and the base height ratio were tested. The number of photos depends on how many orientations for each area being photographed. To acquire a 3-D geometry information, there needs at least two photos of the same object taken from different positions. Figure 2 shows the six horizontal orientations, which the images from the three right hand sides
(UR, R, LR) and the three left hand sides (UL, L, LL) of the object were taken for a complete measurement mode. While in a compact measurement mode, only two photos, which from the position L and the position R, were taken. As for the vertical angle of the camera, Marzan and Karara (1976) shows that 45° is the optimal angle when the object area is to be projected overlaid from two positions [7]. However, to diminish the shadow area hidden behind the structure, a more vertical orientation toward the ground, 60°, was used instead (Fig. 3). With a specific CMOS sensor, the larger the field of view (FOV), the poorer the spatial resolution an image represents. The FOV is a function of the camera height, H, the focal length of a camera, f, and the dimension of the camera CMOS sensor, S. According the triangle similarity theory, the relation between the FOV, the camera height, H, the focal length of a camera, f and the dimension of the camera sensor, S, can be written as:

\[ \text{FOV} = S \cdot \frac{H}{f} \]  

(1)

Figure 4 schematically shows two camera configurations used in the tests. Keeping the same base line, B, and the same FOV, the left hand side configuration with larger base height ratio (B/H) would be able to acquire photos of higher accuracy. The test conditions are listed in Table 1.

![Fig. 2 The six orientations to take photos](image1)

![Fig. 3 The camera oriented 60° downward](image2)

![Fig. 4 Two base height ratios with two focal lengths were tested.](image3)

(left: H_1= 2.5 m, f=20 mm; right: H_2= 5.0 m, f=40 mm)
Table 1. Testing Conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>Overlaid photo numbers of each area</th>
<th>Camera height (m)</th>
<th>Focal length (mm)</th>
<th>Camera orientation toward ground (°)</th>
<th>Shift distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>6</td>
<td>2.5</td>
<td>20</td>
<td>60</td>
<td>1.0</td>
</tr>
<tr>
<td>II</td>
<td>2</td>
<td>2.5</td>
<td>20</td>
<td>60</td>
<td>1.0</td>
</tr>
<tr>
<td>III</td>
<td>6</td>
<td>5</td>
<td>40</td>
<td>60</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Reusing coal ash, which density is around 2.0, is often used as moveable bed material for experimenting which order us to abate the sediment scale effect. Nevertheless, by its dark color, the imagery surface measurement method is normally blocked by performing. To enhance the bed surface reflection and whence the spatial resolution, a lot of white paper dots, of which diameter 6.0 mm, were seeded in the domain (Fig. 5). Meanwhile, with the help of 39 standard pattern targets deployed in the domain, the photos can thus be taken randomly as long as to shot the same area following the rules described above. The pattern targets are 5.0 cm by 5.0 cm square black plate coded with eight 6.0 mm white, round dots (lower left corner of Fig. 5). The Australis 6.01, which is the associated software with these pattern targets, was employed. To speed up the calculating process, the minimum pattern targets number in each images were set to be nine (see Fig. 5). Since the targets have a uniform dimension, it’s a very helpful scale reference itself. In additions, each targets having it’s unique white dots pattern, it’s like seeding 39 codes in the domain which also facilitate the whole reconstruction process. That is, the parameters describing the relation between the photo and the object, say the distance from the camera or the orientation the camera casting toward the object, can be obtained through these seeded pattern targets.

![Fig. 5. Pattern targets and white paper dots were deployed in the domain to be measured.](image-url)
Data verification. Figure 6 shows the distribution of the 19 white paper dots (the white number) for verification and the pattern targets (red characters). The domain was also measured by a total station (TST, Sokkia SET610) for reference. The coordinates (XYZs) of the 19 white paper dots measured by the three photogrammetry cases were plotted together with the TST measured data (Fig. 7). Referring to the TST data, it shows that results from all the three camera configurations cases are in a good agreement with each other and the referred data, except the RMS-Y in case II deviates a little more than the others (Table 2). Since the case II is the case with only two images overlaid for each area, it may thus perform not as good as that of case I.

![Fig. 6](image1.png)

![Fig. 7](image2.png)

Table 2. The standard deviations in each coordinates for the three cases

<table>
<thead>
<tr>
<th>Case</th>
<th>RMS-X</th>
<th>RMS-Y</th>
<th>RMS-Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.014</td>
<td>0.006</td>
<td>0.002</td>
</tr>
<tr>
<td>II</td>
<td>0.014</td>
<td>0.113</td>
<td>0.002</td>
</tr>
<tr>
<td>III</td>
<td>0.015</td>
<td>0.006</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Results and discussions. The bathymetry measured by photogrammetry of different camera configures are shown in Fig. 8 and Fig. 9. The contours show highly similar pattern in Fig 8, where case I and case II are compared, except at the both upper left and the lower right corners, where there seems no white paper dots being detected. The same case, which there is empty reflection near the upper left and the lower right corners, also displayed in Fig. 9, where case II and case III are compared. It was because that there’s no pattern target being deployed near the two corners. Statistic data that automatically calculated by Australis, including the valid photo numbers, the recognized pattern targets numbers and the recognized white paper dots numbers, are shown in Table 2. In case II, as expected, it has the least number of valid photos. However, its performance is surpris-
ingly good in comparison with the other two results. Although there’s only about 1/6 to 1/3 of valid photos compared to those of case I and case III, the recognized pattern targets numbers in case II is only one less than the total deployed. In additions, the recognized white paper dots numbers in case II is about 80% to that of case I. This result makes it clear that the point is not on the number of photos but on the number of the pattern targets and the white paper dots recognized by the software. Since the performance from case II, which using the least number of photos, can achieve the same level as the other two cases, it was then compared with the traditional point gage measurement, plotted in Fig. 10. It shows that the bathymetry pattern obtained from these two methods look alike, except that the contours by photogrammetry appear much more irregular than those of traditional method. This is reasonable since the measuring grids in traditional method were 50 cm away from each other, which horizontal resolution is poorer than the photogrammetry method. On the other hand, the discrepancy shown at the both upper left and the lower right corners again is due to the lack of reflection for the photogrammetry method. Based on this typical case, the required time by photogrammetry, when not counting the time for draining water, was about 1/4 compared to traditional method by point gage.

Conclusions. A close range photogrammetry was applied to measure the bathymetry near a harbor model. Among the parameters affecting the performance, the number of photos and the base height ratio were tested. It shows that, in case the recognized pattern targets and the white paper dots are sufficiently recognized, the photo numbers can be as low as just taking photo from two positions for each area when the software Australis is employed. The base height ratio show less sensitive than the number of photos in the cases tested, however, it needs more tests to make a solid conclusion on this point. The time required for close range photogrammetry to obtain a coastal bathymetry for this typical case study is about 1/4 to the traditional method when the time for draining water is neglected.
Table 3. Statistic data the Australis calculated

<table>
<thead>
<tr>
<th>Case</th>
<th>Valid photo numbers</th>
<th>Recognized target numbers</th>
<th>Recognized white paper dots numbers*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>191</td>
<td>39</td>
<td>3,093</td>
</tr>
<tr>
<td>II</td>
<td>39</td>
<td>38</td>
<td>2,521</td>
</tr>
<tr>
<td>III</td>
<td>124</td>
<td>34</td>
<td>2,838</td>
</tr>
</tbody>
</table>

* 3,200 white paper dots were seeded

Fig. 10. The bathymetry measured by case II (blue line) and by traditional method (green line).
REFERENCES


7. Marzan G.T. and Karara H.M. Rational design for close-range photogrammetry, Department of Civil Engineering, University of Illinois at Urbana-Champaign, 1976.
