ACQUIRING UNDERWATER DSM USING CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT:
Underwater digital surface model (DSM), which is acquired by through water photogrammetry, is affected by light refraction so the resultant DSM is higher than its true value. Previous researches proposed correction procedures to mitigate this effect, but they show the tendency to over-correct the DSM. In this study, we propose a new correction procedure that based on the empirical relation between the DSM value determined from photogrammetry measurement and that obtained by a measuring probe. This new method is validated by comparing the DSMs of a small object acquired in exposed and underwater conditions.

1. INTRODUCTION

Determine the underwater DSM is important for understanding fluvial surface for bed roughness and the sediment process. Through-water close range digital photogrammetry produces incorrect underwater DSM, where the apparent DSM is higher than the true DSM shown in Fig. 1, if the refraction effect of the light ray at the air/water interface were not appropriately treated.

Butler et al. (2002) describes the use of close range digital photogrammetry to measure and monitor the change occurring in submerged river-beds in flume and field environments. Their results show that mean error is -3.5 mm for corrected DEM.

For aerial photogrammetry, Murase et al. (2008) proposed a depth correction method that employing two stereo photo simultaneously. Comparison of the corrected depths with measured depths showed a mean error and standard deviation of 0.06 m and 0.36 m, respectively, for measured depth in the range of 3.4 m to 0.2 m.

In this study, a new depth correction method is proposed, which utilizes the empirical relation between the true depth and apparent depth (Fig. 1). The true depth has the correct z value of the underwater DSM and the apparent depth has a higher z value, which needs to be corrected for. This new method is evaluated using a small object placed in a laboratory setup and the root mean square error (RMSE) shows higher accuracy.

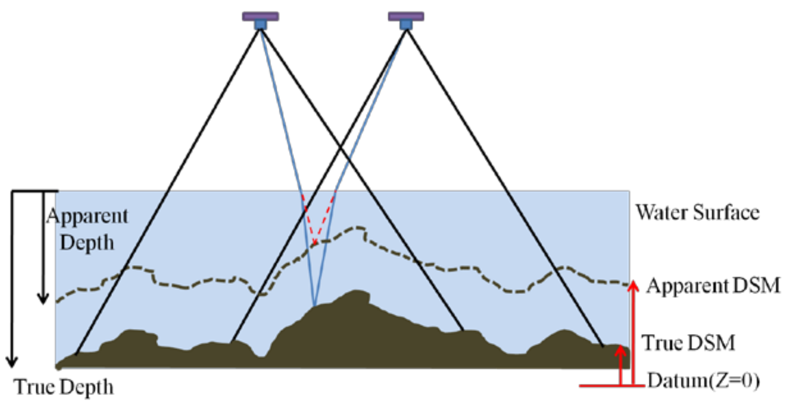

Fig. 1. The blue lines refract in the water and located in the true DSM. The red lines go straight into water and converge in apparent depth.

METHODOLOGY

2.1 Depth correction Methods

Method I (Bulter et al., 2002):
The depth correction method by Bulter et al. (2002) is

$$h = \frac{\mathbf{h_A tanr}}{\mathbf{tan}\left(\mathbf{sin^{-1}}\left(\frac{\mathbf{sinr}}{\mathbf{n}}\right)\right)}, \tag{1}$$

where h is the true depth, h_A is the apparent depth, and r is the angle of refraction shown in Fig. 2.

Method II (Murase et al., 2008):
The depth correction method by Murase et al. (2008) is

$$h = \frac{\mathbf{tanr_1 \cdot cos\theta_1 + tanr_2 \cdot cos\theta_2}}{\mathbf{tani_1 \cdot cos\theta_1 + tani_2 \cdot cos\theta_2}} \cdot \mathbf{h_A}, \tag{2}$$

where

$$\cos\theta_1 = \frac{X_A - X_{S1}}{D_1} \tag{3}$$

and

$$\cos\theta_2 = \frac{X_{S2} - X_A}{D_2}. \tag{4}$$

X_{S1} and X_{S2} are the positions of the cameras, XA is the position of the apparent DSM, D_1 and D_2 are the horizontal distances between the camera position and DSM measurement, and r and i are the refraction and incident angles, where the subscripts are for the stereo pair, shown in Fig.2.

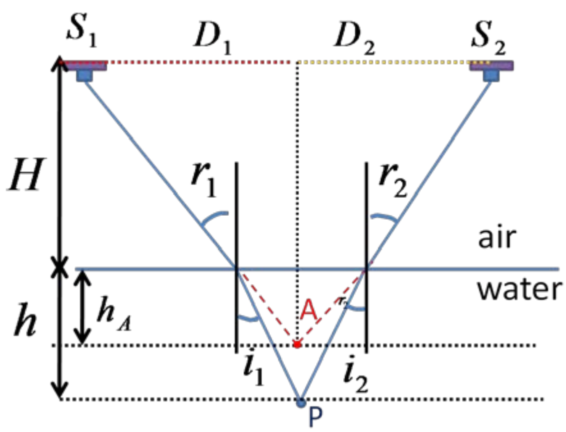

Fig. 2.Geomertry of two medium photogrammetry.

Method III (our approach):
It is obvious that the corrected depth shown in Bulter et al. (2002) and Murase et al. (2008) are overly corrected. To resolve this, we propose using the empirical relation between the true depth and apparent depth from a limited depth measurement. After the regression relation is constructed, it can be applied to derive the corrected depth for the whole model.

2.2 Camera and accessories

In this research, Nikon D200 is used, the pixel size is 0.0061 mm, the width is 3872 and height is 2592, the focal length is set 60 mm. A box with dimensions of 20 cm × 30 cm × 40 cm is set for experiment. Another tool, retro-code is used to be features and automated identified in photos during aerial triangulation. Retro-codes consist of 8 red dots, each arrangement creates unique code. The 3D probe is composed of a long stick and two assisted branch is shown in Fig. 3(a). There are 5 dots in the stick and two dots in each branch as a measurement features. The peak of the stick is used touching surface of model in the submerge situation as a true depth for correction. A bowl-shaped model with the diameter of 15 cm and the height of 3 cm is covered by the Ottawa standard soil and is used to mimic a spring-pot induced by underwater injection is shown in Fig. 3(b)

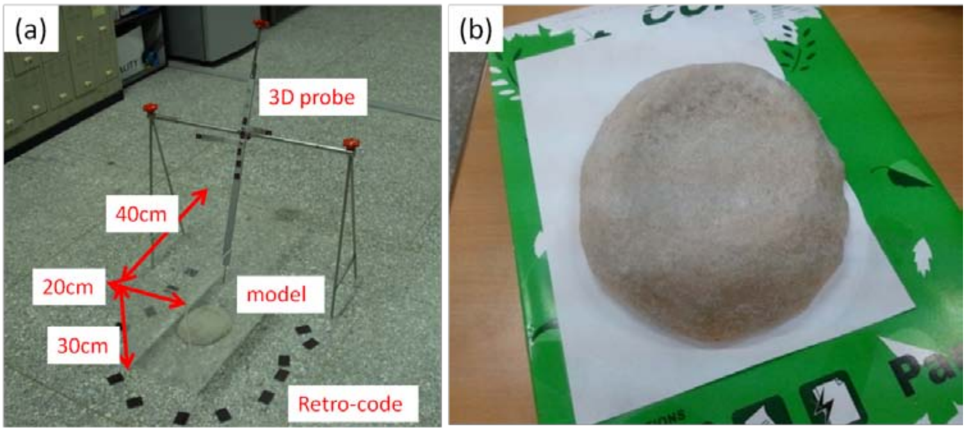

Fig. 3. The assisted equipments (a) the box and assisted equipments (b) experiment model

2.3 Photogrammetry procedure

There are four steps in taking pictures. For building a 3D model, Interior orientation (IO) of camera and exterior orientation (EO) of every camera exposure is essentially. Prior step is camera calibration, there are 16 pictures input to the process. The estimate accuracy of image is 0.2 pixel. Thereafter, ruler calibration is required, there are eight positions determined including seven dots and the peak set in the 3D ruler. Make the transform matrix between each position. In the submerged case, by solving the observation of seven dots, the peak position can be determined as a true value.

The second step is aerial triangulation to produce the EO of non-water and submerged water case. Input 24 images, respectively. Non-water procedure is used as a validation dataset. And the submerge water case is used as correction observations. Coordinates system is defined by producer. The origin is set in certain retro-code, axis of direction X Y and Z also determined by producer. The Z value may be negative in the experiments.

2.4 Software

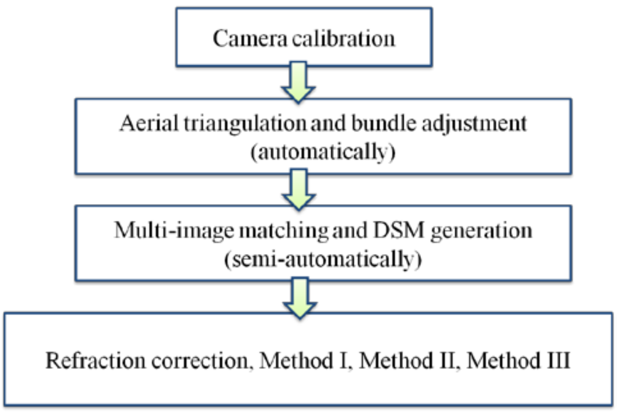

Fig. 4. Flowchart of procedure

The flow chart of the procedure is shown in Fig. 4. The software iWitness is used to calculate the relative position and it makes EO and IO solution (Fig. 5). Close-range matching software, CLORAMA, is used for generation point clouds and by 3D TIN interpolation building DSM.

At iWitness process, constructing the aerial triangulation space coordinate system, retro-codes located at different directions around the box. The most important thing is fixed camera focal length as the results of the calibration result. Import 24 images to iWitness, then import and fix camera parameters from camera calibration, and run the Autocal function.

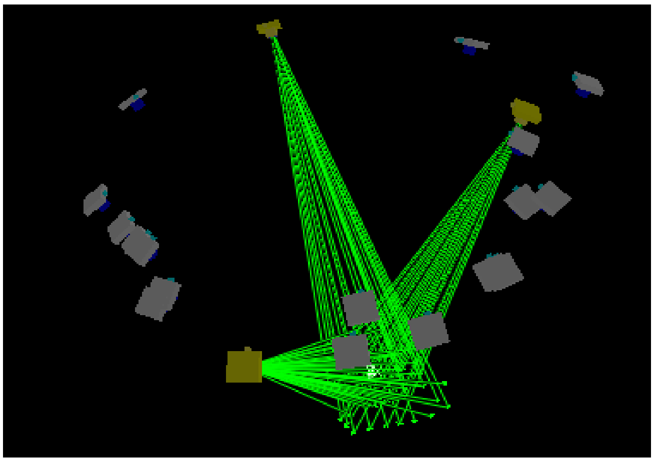

Fig. 5. The distribution and intersection of cameras locate in iWitness.

Utilize the software, CLORAMA to have point cloud generation. Input the value of average object height and grid space of surface model depends on the observation and requirements and then input the Max and Min height imaging area. The photos put into the CLORAMA almost take vertically. Multiple image matching is required with grid space of final DSM of 0.5 mm. In the study, two groups of images are input to the CLORAMA, the first one is non-water photos and the other is submerged photos. As shown in Fig. 6 (a) the non-water DSM is smooth and converges tightly. On the other hand the submerged DSM increases noises and is roughness in the surface.

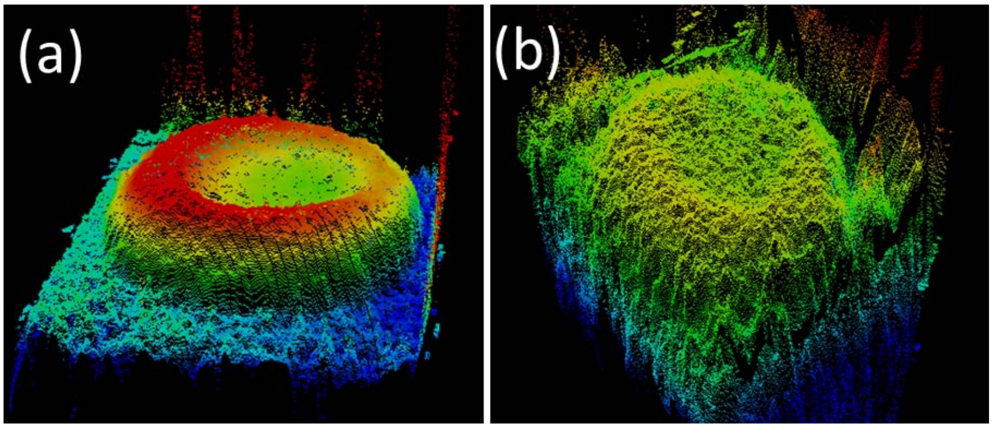

Fig. 6. The result of CLORAMA(a) Non-water DSM of test area(b) submerged DSM of test area.

3. RESULT

Fig. 7 shows the regression result between the apparent water and the true depth obtained from the 3D probe estimated from 16 measurements their relationship

$$h_{3D} = 0.9895h_A - 8.3428,$$

has a r^2 value of 0.79. The origin is set in 190 mm. Therefore the depth value is negative. Compare method I (Fig.8 (a)), method II ((Fig.8 (b)) and method III (Fig.8 (c)). Correction from one image is the most dispersed and in-situ experiment shows the best accuracy of all. In the profile shown in Fig. 9 the green line is the result of Bulter et al., (2002), red line is the result of Murase et al., (2008), and yellow line corresponds to in-situ method. Non-water depth applies in blue line. The figure shows that yellow line fits the true depth tightly. At the depth of 25 mm, all of correction methods have minimum records. The green line and red line at a position of -180 to -170 corresponds to the depth 10~20 mm in Fig. 10 appears serious over-correct. Contrast to Fig. 11. The overall RMSE calculate all points of DSM of different correction method depth $Z(i)$ and true depth $Z_{true}(i)$ which is produced from non-water DSM.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z(i)-Z_{true}(i))^2}{n}} \quad (5)$$

The RMSE of uncorrected is 8.145 mm and the best one is 2.00 mm of the proposed method in the research. At different water depth, method III all shows the minimum RMSE readings.

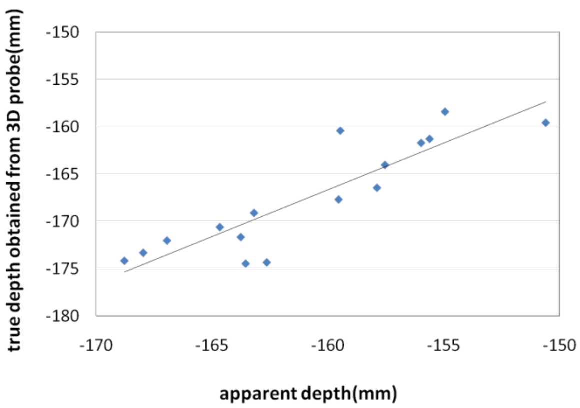

Fig. 7. The regression of the estimate depth and apparent depth.

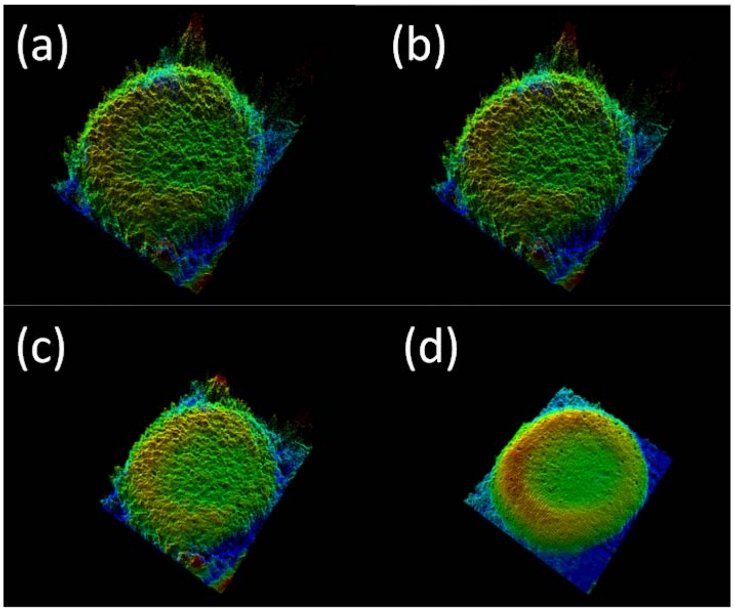

Fig. 8. The regression of the estimate depth and apparent depth. (a) the correction result from method I (b) the correction result from method II (c) the correction result from method III

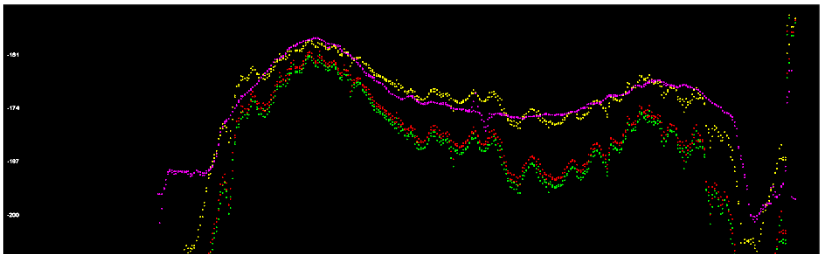

Fig. 9. Red line is the correction depth of method I, green line is the correction depth of method II, yellow line the correction depth of method III and blue is non-water depth.

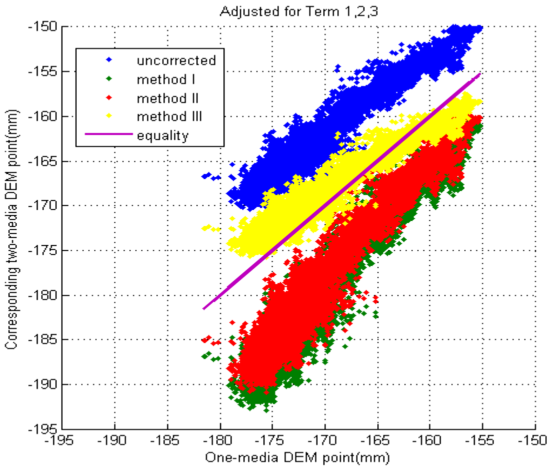

Fig. 10. The result of different correction method of test area. The blue line is apparent depth. Purple line is equality. And green line is method I resultant the red one is correct from method II. Green line is the correction result of method III

water depth(mm)	10~15	15~20	20~25	25~30	Overall
Uncorrected	8.32	8.1221	7.2805	5.8844	8.145
Method I	7.5109	5.2108	3.0802	3.2645	6.9539
Method II	6.1878	4.2094	2.3091	2.569	5.7084
Method III	2.0803	1.9761	1.1521	1.3702	2.0063

Fig. 11. The RMSE of different depth and overall result.

4. CONCLUSION

In the study, the purpose is to do the water depth correction, the previous study Method I and II shows over correct the depth bias. And the proposed method produces underwater DSM. Use the assisted equipment to correct the water depth gives the minimum RMSE. It has better accuracy and simple implementation. The limit is that in situ measurement is required.

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