A fully automated and accurate method for 3D reconstruction of unsaturated soil specimens

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ABSTRACT: 3D reconstruction technique is gaining its application in geotechnical engineering. However, a fully automated and accurate method for 3D reconstruction of unsaturated soil specimens in triaxial tests is still missing. In this paper, we developed a method for 3D reconstruction from multiple views with combined use of computer vision technique and photogrammetry. In this method, coded target detection and camera calibration was performed first to obtain the input to the 3D reconstruction process. Then the camera poses and 3D points were estimated from the first two views, and all the rest of views could be processed. Validation test results on a cylinder demonstrated that the proposed method can achieve very good accuracy. Combining this method with a newly proposed ray tracing technique, a highly accurate and automated method for measuring the volume changes of unsaturated soil specimens in triaxial tests can be obtained

1 INTRODUCTION

Multiview 3D reconstruction is a technology that allows the creation of 3D models of a given target scene from a series of 2D overlapping images obtained from a digital camera (Favalli et al. 2012). Due to its low cost and convenience, this technology has become more and more popular in geotechnical engineering. Kitahra et al. (2016) used 3D models obtained from multiple-view images to simulate rock fall. Oats et al. (2017) developed a method for retaining wall assessment based on 3D photogrammetry technique.

While promising, conventional 3D reconstruction technique still suffers from significant limitation when dealing with optically challenging objects, like the unsaturated soil specimen in triaxial tests where multiple optical media (air, acrylic cell, water) are involved. This is because refraction will occur at the interfaces of two optical media, and conventional 3D reconstruction technique cannot be applied directly.

To overcome this limitation, Zhang et al. (2015) proposed a method which integrated a ray tracing technique and 3D photogrammetry to correct the refraction and reconstruct the 3D models of unsaturated soil specimens. Based on these 3D models, the volume change of unsaturated soil samples was successfully calculated. In contrast with conventional 3D modeling technique, this method has extended the 3D photogrammetric technique to multiple optical media, which seems a very promising technique for measurement of volume changes of unsaturated soil specimen in triaxial tests since it only requires one commercially available camera to take images from any arbitrary directions and locations. Additionally, both global and localized deformation of the soil samples can be measured and this method has been reported to have very good accuracy (Zhang et al. 2015; Li et al. 2015).

Many commercial software packages for image-based 3D modeling are available, but a program capable of deriving an accurate 3D model of unsaturated soil specimens considering refraction in a fully automated and efficient way from a series 2D experimental images is still missing.

Recent advancements in computer vision has enabled 3D modeling process to be highly efficient and automated. But its accuracy is rarely checked out and most results are primarily for visualization purposes (Barazzettia et al. 2009).

In this paper, we present a method for fully automated 3D modeling of unsaturated soil specimens based on combined use of photogrammetry and computer vision techniques. Since as mentioned earlier the accuracy is a big concern if computer vision technique is used for geotechnical purposes, the accuracy of our method will be carefully evaluated. It is worth noting that this method is easy to be integrated with the ray tracing technique proposed by Zhang et al. (2015). Thus, a fully automated and accurate method for 3D modeling of unsaturated soil samples considering refraction can be obtained.

2 CODED TARGET DETECTION

The first step of 3D modelling of soil specimen is to find the identical image points in multiple images, which is often referred to as the correspondence problem (Ahn and Rauh 2001). Detecting the interest points and finding the matches between different images has long been recognized as one of the most difficult problems in 3D reconstruction (Hung et al. 1998; Tang et al. 2002). To overcome this problem, coded targets which are widely used in photogrammetry are introduced. They are often placed on the objects before images are taken. Three dimensional coordinates of the center of these coded targets are obtained and point cloud is thus generated. Therefore, we only need to detect these limited coded targets, and the task of finding a set of point correspondences can be simplified immediately.

Xia et al. (2017) developed a high-accuracy method for automatic detection of coded targets. The method used for coded target detection in this paper is the same as Xia et al. (2017). The major procedures will consequently only be briefly recalled here, while a more detailed description can be found in Xia et al. (2017). The Image segmentation is performed first to extract single patch of coded targets from images. Then a signature-based feature extraction method is used to distinguish a single coded target from other coded targets. In order to eliminate detection errors caused by projection, ellipses are normalized into circles based on image processing technique. It has been demonstrated that the detection rate of this coded target detection method is nearly 100% (Xia et al. 2017).

3 3D MODELING FROM MULTIPLE VIEWS

3.1 *Camera calibration with Matlab*

Camera calibration in the context of 3D modelling is the process of determining the internal camera geometric and optical characteristics (intrinsic parameters) (Tsai 1987). The accuracy of camera calibration will largely influence the performance of 3D modelling.

Zhang (2000) proposed a flexible new technique for camera calibration using planar plane calibration sheet, which is perhaps the most popular camera calibration method in computer vision community. The calibration procedures have been implemented in Matlab toolbox based on this method. In this paper, we used Single Camera Calibration App in Matlab Computer Vision System Toolbox to obtain the camera parameters, which include focal length, principal point, lens distortion coefficients and so on.

3.2 *3D reconstruction from multiple views workflow*

3.2.1 *Point Matching between two neighbouring views*

The coded target detection and camera calibration results described in the previous sections serve as inputs to the 3D modelling from multiple views. We have input file storing the information regarding the coded target ID, photo ID, pixel coordinates for each coded target in each image. Since 3D modelling from multiple views requires the overlapping interest points (coded targets) between each two neighbouring views, the overlapping interest points for each two neighbouring views are matched first based on their coded target IDs and photo IDs. These matched points are then stored and will be used in the following procedures.

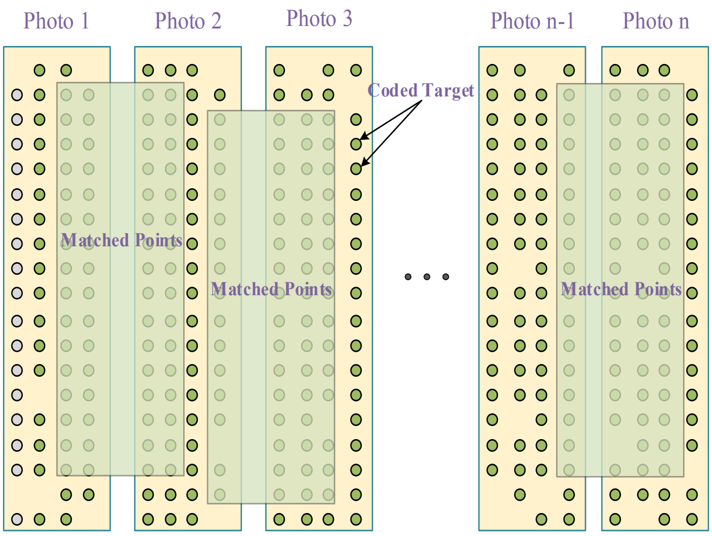

Figure 1. Point matching for the coded targets between each two neighbouring views

3.2.2 *3D reconstruction from the first two views*

3D modelling requires a global coordinate system to be set so that all the 3D locations and/or orientations of the interest points and camera poses can be described in a unified coordinate system. In this paper, the origin of the global coordinate system was set at the optical centre of the first camera. While a more detailed description can be found in Hartley and Zisserman (2003), the primary steps are listed as follows:

(1) Estimate the fundamental matrix using epipolar geometry.
(2) Estimate the motion of the second camera.
(3) Use triangulation to determine the 3D locations of the matched points.

3.2.3 *3D reconstruction from the rest of views*

Based on the 3D modelling results from the first two views, all the rest of views can be processed using the same procedures which are described in this step. Beginning from the third view to the last view, the pairwise point matches and known 3D points obtained from the previous steps are used to estimate the camera pose of the current view relative to the first view, which is called photo resection. A viewSet object is created to store and update the data regarding each view. The 3D modelling algorithm consists the following steps:

(1) Use photo resection to estimate the pose of current view relative to the first view.
(2) Use triangulation to determine the initial 3D locations of interest points
(3) Use bundle adjustment to refine the camera poses and 3D points.
(4) Use mean reprojection error to judge whether the motion estimation for current view is good or not. If the mean reprojection error is large, improve the photo resection. Otherwise, restore and update the camera poses and 3D points
(5) Go to the next view and repeat the above processes until all the views are processed.
(6) Add a global scale to the project.

The flowchart of the 3D modelling from multiple views is shown in Fig.2. And the whole process was implemented into a Matlab program developed by ourselves.

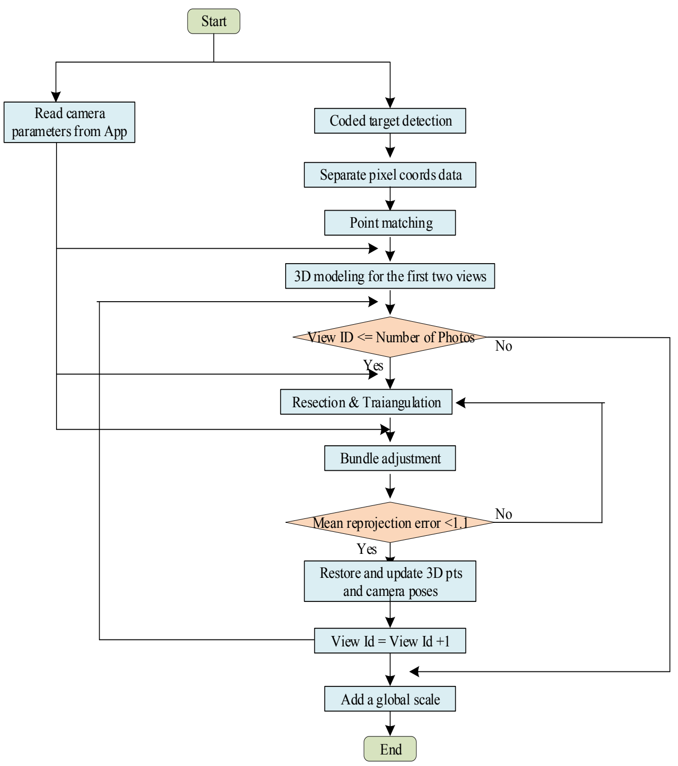

Figure 2. Flowchart for the developed method

4 PERFORMANCE AND ACCURACY ANALYSIS

4.1 *Performance of 3D reconstruction*

To evaluate the performance of the developed method, 3D modelling tests on a cylinder were implemented. Totally 32 images were taken in 360 degrees around the target cylinder. Then these images were processed by our developed Matlab program. The camera poses and reconstructed 3D model of the cylinder are shown in Fig.3. and Fig. 4., respectively. The results show that our method is capable of processing all the images and reconstructing the 3D models of the target cylinder successfully. It is worth noting that the whole 3D modelling process is fast and highly automated.

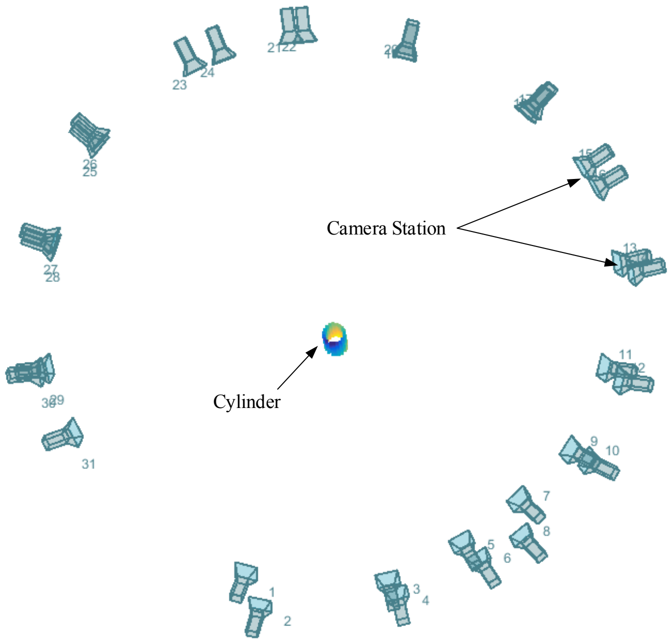

Figure 3. Camera station obtained from our method

Figure 4. 3D models obtained from our method

4.2 *Accuracy analysis*

The accuracy of our method was validated by measuring the height of the cylinder. We compared our results with thoses obtained by PhotoModeler, a close-range photogrammetry software package which is well known for its accurate 3D modelling.

The results showed that the relative error from our method was 0.067%, while the relative error from PhotoModeler was 0.05%, which indicated that the accuracy of our method is comparable to commercial software. It is interesting to note that, although in conventional computer vision projects we do not pay much attention to the accuracy since many projects are only for visualization purposes, we can still achieve very good accuracy when combining the computer vision technique with photogrammetry. One reason for good accuracy is probably because we used coded target detection method instead of feature detection in conventional computer vision projects, which can avoid outliers and improve the accuracy.

5 SUMMARY AND CONCLUSION

This paper presented a method capable of creating accurate 3D models of target objects, like unsaturated soil specimens, from multiple views in a highly automated way. Combined use of computer vision technique and photogrammetry enables the 3D reconstruction process to be highly automated and accurate. The whole process was implemented into a Matlab program. Validation test results indicate that the relative error of our method is 0.067%.

This method is easy to be integrated with a newly proposed ray tracing technique by Zhang et al. (2015), and a fully automated and accurate program for measuring volume changes of unsaturated soil specimens in triaxial tests can be obtained.

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