Automatic Detection of Coded Targets for Rapid Measurement of Volume Changes of Unsaturated Soil Specimens in Triaxial Tests

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ABSTRACT: A photogrammetry-based method has recently been proposed to measure volume change of unsaturated soil specimens during triaxial tests. It only requires a commercially available digital camera to take images from which the three-dimensional model of the soil specimen can be reconstructed. The images can be taken from any arbitrary locations and directions. This newly proposed method has been proved to be simple, flexible, cost-effective, and accurate. One limitation of the proposed method was that the detection of the targets on the soil specimen was tedious and time-consuming at its present version. This paper presents a method to automatically detect the coded targets for rapid deformation measurements on unsaturated soil specimens during triaxial tests. The identical coded targets in multiple images are recognized using a signature-based shape feature extraction technique. A unique point ID is thus generated for these multiple identical coded targets. Validation tests have been performed to demonstrate the effectiveness and accuracy of the proposed approach.

1 INTRODUCTION

A photogrammetry-based method has recently been proposed to reconstruct the 3D model of unsaturated soil specimen in the triaxial tests. Based on the 3D model, the volume change of unsaturated soil samples is thus calculated (Zhang et al. 2015, Li et al. 2015). In contrast with conventional photogrammetric technique, this method has extended the photogrammetric technique to multiple optical media. This seems a very promising technique for measurement of volume changes of unsaturated soil specimen in triaxial test since it only requires a commercially available camera to take images from which the three-dimensional model is reconstructed. Additionally, these images can be taken from any arbitrary directions and locations.

One major task of reconstructing the 3D model 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 centre 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.

However, the method of using coded targets still suffers from the low detection accuracy. This low detection accuracy primarily results from the large deviation of shooting direction from the coded targets direction, and the projection of the circular coded targets will be far from being circular. Therefore, it usually takes much effort to correct the false detection, which makes the newly proposed photogrammetry-based method tedious and time-consuming at its present version.

This paper deals with the above issue. The aim of this study is to develop a high-accuracy method for automatic detection of coded targets. To this end, 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. To eliminate detection errors caused by projection, ellipses are normalized into circles based on image processing technique. Results from validation tests are presented to demonstrate the accuracy of our proposed method.

2 CODED TARGET DESIGN

The coded targets we used, printed on the coded target sheet, are provided by PhotoModeler Scanner from EOS system Inc. As we can see in Figure 1, every coded target is composed of several concentric rings. We divide the coded target into 12 parts based on the angle. Each part is a sector with a central angle of 30 degrees. It is worth mentioning that there are only two types of sectors, either a smaller one or a larger one. Due to the many possibilities of sector arrangement, these coded targets can achieve many code possibilities.

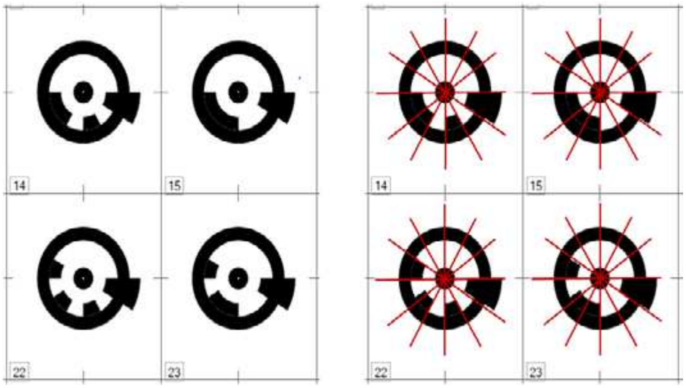
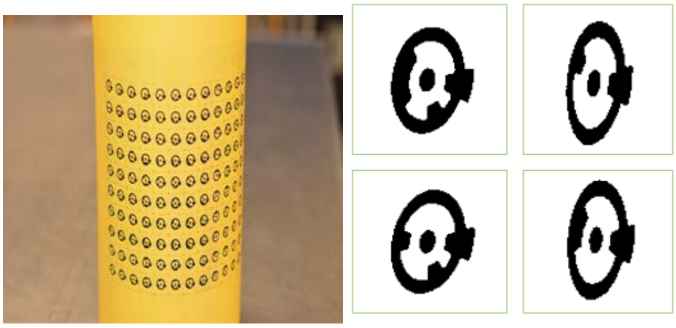


Figure 1. Coded target design.

3 IMAGE SEGMENTATION

Image segmentation partitions a digital image into distinct regions that represent objects or features of interests in the image and is usually the first step of analysing an image automatically (Efford 2000). In our case, we want to extract single patch of coded targets. The following procedures are all based on these coded target patches.

The process of segmentation starts with converting the RGB image into HSV colour space, which aims to improve its robustness to lighting changes. Then an HSV colour map represented by an m-by-3 matrix H can be generated. The columns of the matrix H represent hue, saturation and value, respectively. The threshold-based segmentation is employed to convert the HSV image to a binary image by examining the intensity value of each pixel. Then blob analysis is performed to label connected components, which are called blobs, in the binary image. We remove very small blobs which are not likely to be coded targets by examining the area. Finally, square patch which contains the coded target is extracted from the images. The coded target patches extracted from the original image are shown in Figure 2.



(a) (b)

Figure 2. (a) Input image (b) Typical coded target patches extracted from (a)

4 A SIGNATURE-BASED SHAPE FEATURE EXTRACTION METHOD

4.1 *Signature-based feature representation and description*

After the image has been segmented as described in the last section, we need choose some descriptors to represent and describe the features. In image processing, a signature is such a descriptor that can present the boundary characteristics of a shape feature. A signature is a simple 1-D functional representation of a boundary and can be generated by plotting the distance from the centroid to the boundary as a function of angle (Gonzalez and Woods 2002), as illustrated in Fig. 3.

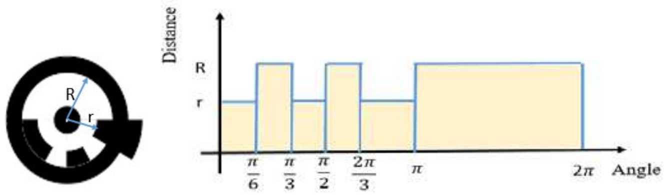
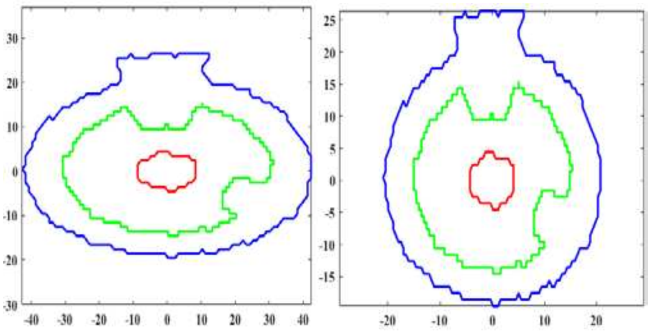


Figure 3. Distance-versus-angle signature for the coded target boundary

4.2 *Our proposed method*

The basic idea of our approach is to use signatures to present and describe the boundaries of each coded target. Then the boundary histograms for each coded target can be generated. Each coded target has a unique histogram, and we can use this histogram to easily represent and recognize the coded targets.

In the above discussion we have assumed that the coded targets are ideally circular. However, this is rarely the case and it is very likely that the coded targets in the images are elliptical due to projection. Thus, the histograms become much more irregular which makes the problem more challenging. The case becomes even worse when the shooting direction deviates far from the normal direction of the object surface. This is also the reason why many existing methods for coded target detection suffer from low detection accuracy. To overcome this problem, blob analysis is performed first to fit the coded targets using ellipses. Then we rotate the coded target to have the major axial parallel to the x-axis. After that we translate the boundaries of the coded target so that the centroid coincided with the origin. Finally, the ellipses are normalized to circles by reducing the length of the major axis. The boundaries of the coded targets before and after normalization is shown in Figure 4.



(a) (b)

Figure 4. Boundaries of the coded target before and after normalization: (a) Before normalization (b) After normalization

Starting point is another important issue we need to address. This is because signatures generated by the above method are dependent on rotation. There are plenty of possibilities to plot the boundary histogram with an undetermined starting point. Therefore, we need to figure out and fix the starting point before we can get a unique histogram as well as a unique point ID for the coded target. We solved this problem by detecting the bulge on the outer boundary. This idea is based on the observation that the location of the bulge on the outer boundary is fixed between different coded targets. Hence, we calculate the gradient of the outer boundary, and there are generally two sudden changes of gradient values. We always set the first sudden change as the starting point. Then we rearrange the points on the inner boundary and plot the histogram. We also assume that “1” denotes the higher distance value while “0” denotes the lower distance value. Hence, we obtain twelve binary numbers in order. Finally, we transform the list of binary numbers into a decimal number and use this number as the point ID for the coded target.

5 EXPERIMENTAL VALIDATION OF THE PROPOSED METHOD

We evaluated the performance of our proposed method with different images. Test results shows that our proposed method can achieve nearly 100% detection rate. Figure 5 shows an original image of coded targets that placed on soil sample and the point IDs for the coded targets obtained by our proposed method. It is worth noting that even for the coded targets close to the edge of the image, for example, the first column of the coded targets, we are still able to detect them correctly. This is a good improvement in detection accuracy compared to conventional methods since the coded targets that are close to the image edge are often misrecognized using existing methods.

(a) (b)

Figure 5. Detection results of our method: (a) Original image (b) Identified coded targets with point IDs

6 SUMMARY AND CONCLUSION

We have presented an approach that allows efficient and accurate coded target recognition for rapid measurement of the volume changes of unsaturated soil specimen in triaxial tests. Central to this approach is a signature-based method to represent and describe the shape features of the coded targets. Elliptical coded targets appeared in images are normalized into circular ones by image analysis. Validation test results indicate that our proposed method can achieve very good accuracy. The proposed method has the potential to improve both the accuracy and efficiency of three-dimensional reconstruction of the unsaturated soil specimens as well as other objects to be measured.

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