Application Research of SfM in Consolidation Grouting Material Performance

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Abstract. The main purpose of this paper is to develop a new evaluation method based on structure from motion (SfM) for consolidation grouting material performance. An artificial sand object, which have been injected by consolidation grouting materials with different proportion, was built in an experimental room. Based on SfM technique, the model of the artificial sand object could be built with only some unordered images, correspondingly, the volume could be calculated and compared in order to evaluate the performance of the consolidation grouting material with different proportion.

Introduction

Consolidation grouting is an important means for anti-seepage and reinforcement [1]. The development and usage of grouting materials become more and more necessary for improving the quality of reinforcement engineering[2,3]. Therefore, an evaluation method should be researched for the performance of consolidation grouting material.

The purpose of this paper is to develop a new method for quickly and accurately evaluating the performance of consolidation grouting material. For this research, an artificial sand object was built in an experimental room, and then different materials could be injected into the object respectively. After the sand object solidified, the surrounding sand were removed so that the solidified sand part could be analyzed and assessed. For this purpose, the shapes have to be virtually preserved in terms of a 3D model which enables subsequent quantitative and qualitative analysis.

As a primary technique of computer vision, SfM is mainly used for 3D scene geometry reconstruction from a set of images of a static scene. In recent years, SfM has been successfully applied in more and more areas, including cultural heritage [4], medical science [5] and so on. In this paper, SfM has been applied for the 3D recording of these shapes. The new method used Nikon DSLR for image data acquiring and AgiSoft PhotoScan for 3D modeling. The volume of vertical sections of the dike then could be calculated by using Geomagic Studio, and the distribution of consolidation grouting materials in each section could be induced.

The rest of this paper is organized as follows. Background of the project is introduced in Section 2. Then the generation of 3D model with real scale is described in 3 Section 3. In Section 4, the content about volume calculation and discussion are presented. At last, some conclusions have been got in Section 5.

Background of Project

To validate the new evaluation method for consolidation grouting materials performance presented in this paper, an artificial sand object was built in an experimental room. The grouting material was injected into the object. Then the surrounding sand was removed with an excavator after the material was fully solidified. Only the solid shapes were remained, which look like some connected columns (Figure 1). The size of the remaining shapes was approximately 1.4m×0.6m×1.6m.
Generation of 3D Model with Real Scale

Data Acquisition

SfM is a technique of estimating camera position and motion and reconstructing the 3D scene by use of a sequence of 2D images. The advantage of SfM is its simplicity, i.e., a 3D model can be constructed with digital images without knowledge of camera locations and optics information. Moreover, SfM model can be generated with any set of photographs which contain sufficient image overlap and adequate quality. Therefore, it’s not difficult to conclude that the quality of the generated dense point cloud data largely depends on both the quality of all images, including resolution, and the clarity of the shape textures.

In this paper, a camera Nikon D700 combined with a 50 mm lens, was used for image acquisition. As the challenging dark lightning conditions in the experimental room and the use of the flash light might be both disadvantageous for the SfM processing, it was necessary to find a compromise between ISO, exposure time and aperture settings.

From experience, the best parameters configuration of camera is set as Table 1.

<table>
<thead>
<tr>
<th>Camera Model</th>
<th>Lens [mm]</th>
<th>ISO</th>
<th>Shutter [s]</th>
<th>Aperture</th>
<th>Overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D700</td>
<td>50</td>
<td>800</td>
<td>1/50</td>
<td>f/9</td>
<td>≥60%</td>
</tr>
</tbody>
</table>

Considering the irregular shape of the object and occlusion, more than two hundred photos were taken sequentially around the shape at equal small angles interval and similar distance to the object. And three groups were divided from top to bottom. The overlaps of both vertical and horizontal direction have reached more than 60%. After quality estimation, 152 images were used for dense point cloud generation.

Data Processing

The process of SfM model generation mainly includes three stages.

The first stage is image alignment which could be finished by use of key points. Taking a pair of images as an example, more than three pairs of key points are necessary for alignment. Key points could be extracted from some features in each image which are invariant to the image scaling as well as rotation. And the number of key points in an image mainly depends on image texture and resolution [6].

Figure 1. Picture of the irregular shapes.
The second stage is generation of sparse point cloud model. With the aligned images, a sparse point cloud model composed by a group of key points was built. In this paper, there are about 18,574 key points extracted from images sequence, the model of which is shown in Figure 2.

![Figure 2. The sparse 3D model composed of 18574 key points.](image1)

The dense point cloud model could be built according to the camera position and orientation for each image, which are determined during the process of sparse point cloud model generation. This is the third stage for SfM model generation. Finally, a dense point cloud model with 7,397,846 points is obtained. So high density as well as corresponding color information made the object appear a good visual texture (Fig 6.).

![Figure 3. The dense 3D model composed of 7,397,846 points.](image2)

**Scale Unifying Method of SfM Model**

As SfM dense point cloud model is defined in an arbitrary coordinate system, the model is not in a real scale, which is not suitable for volume calculation and analysis. Therefore, before further process, a correct scaling of the SfM model should be provided, i.e., a solution should be find to transform the model into a real scale. Only with the real scale, can volume calculation and analysis work accurately.

Considering the analysis of the above, a direct method for scale estimation based on ground control points (i.e., markers) has been applied in this paper. Twelve ground control points are set on the body of the sand object, whose absolute coordinates are measured by use of total station.
The estimation of SfM model scale is to transform the local coordinate system to the same coordinate system with ground control points. For this purpose, twelve corresponding markers were selected interactively from the SfM model, which is shown as Figure 4.

![Figure 4. Distribution of corresponding markers.](image)

After coordinate system transformation, the dense point cloud model has been in a real scale. Errors of corresponding markers are listed in Table 2. The total errors of $\Delta X$, $\Delta Y$, $\Delta Z$ and $\Delta$ are 0.014m, 0.010m, 0.003m and 0.018m respectively.

<table>
<thead>
<tr>
<th>Points ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta X$[m]</td>
<td>0.011</td>
<td>0.010</td>
<td>0.017</td>
<td>0.009</td>
<td>0.009</td>
<td>0.016</td>
<td>-0.025</td>
<td>-0.017</td>
<td>-0.014</td>
<td>-0.011</td>
<td>-0.013</td>
<td>0.007</td>
</tr>
<tr>
<td>$\Delta Y$[m]</td>
<td>0.007</td>
<td>0.011</td>
<td>0.014</td>
<td>-0.018</td>
<td>-0.013</td>
<td>-0.015</td>
<td>-0.001</td>
<td>0.009</td>
<td>0.007</td>
<td>-0.006</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>$\Delta Z$[m]</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.000</td>
<td>-0.004</td>
<td>-0.003</td>
<td>0.003</td>
<td>-0.005</td>
<td>-0.001</td>
<td>-0.001</td>
<td>0.002</td>
<td>-0.001</td>
</tr>
<tr>
<td>$\Delta$[m]</td>
<td>0.014</td>
<td>0.015</td>
<td>0.022</td>
<td>0.020</td>
<td>0.016</td>
<td>0.022</td>
<td>0.025</td>
<td>0.019</td>
<td>0.015</td>
<td>0.013</td>
<td>0.014</td>
<td>0.007</td>
</tr>
</tbody>
</table>

**Volume Calculation and Discussion**

**Volume Calculation**

The dense point cloud model should be imported into the third-party software (such as Geomagic Studio in this paper) for further reconstruction and volume calculation. After a series of post-processing steps including elimination of disconnected components and outliers, reduction of noise and uniform sample, a triangulated 3D SfM model is generated (Fig 5.).

![Figure 5. A triangulated 3D model.](image)
The model was divided into 8 parts in vertical direction, and the height of each part was 0.2m. The volume for each part as well as the total volume of 3D model are shown in Table 3.

<table>
<thead>
<tr>
<th>Parts ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔH [m]</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>1.252</td>
</tr>
<tr>
<td>V/[m³]</td>
<td>0.025</td>
<td>0.103</td>
<td>0.158</td>
<td>0.195</td>
<td>0.237</td>
<td>0.269</td>
<td>0.265</td>
<td></td>
</tr>
</tbody>
</table>

Discussion
The 3D model generation as well as volume calculation with SfM shows that errors inevitably exist in the procedure of coordinate transformation, which affects the accuracy of the generated model to some extent. However, SfM is superior both in data acquisition time and modeling quality, which provides a fast and effective means for evaluation of consolidation grouting materials performance.

Summary
In this paper, a new evaluation method for consolidation grouting materials performance is presented by volume calculation based on 3D modeling with SfM. During image data acquisition, although images could be acquired at a relative random way, taking an appropriate imaging configuration, enhancing light condition and keeping enough overlap between images are all helpful to guarantee complete cover of research area, which would improve the accuracy dense model generation. Besides, as SfM model is defined in any local coordinate system, it’s necessary to set a series of ground control points with absolute coordinates on the body of the irregular object to transform the model to a real scale.

References