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A Study on the Quality of Photometric Scanning Under Variable Illumination Conditions

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Abstract

The conventional scan methods are based on a laser scanner and a depth camera, which requires high cost and complicated post-processing. Whereas in photometric scanning method, the 3D modeling data is acquired through multi-view images. This is advantageous compared to the other methods. The quality of a photometric 3D model depends on the environmental conditions or the object characteristics, but the quality is lower as compared to other methods. Therefore, various methods for improving the quality of photometric scanning are being studied. In this paper, we aim to investigate the effect of illumination conditions on the quality of photometric scanning data. To do this, 'Moai' statue is 3D printed with a size of 600 (H) × 1,000 (V) × 600 (D). The printed object is photographed under the hard light and soft light environments. We obtained the modeling data by photometric scanning method and compared it with the ground truth of 'Moai'. The 'Point-to-Point' method used to analyseanalyze the modeling data using open source tool 'CloudCompare'. As a result of comparison, it is confirmed that the standard deviation value of the 3D model generated under the soft light is 0.090686 and the standard deviation value of the 3D model generated under the hard light is 0.039954. This proves that the higher quality 3D modeling data can be obtained in a hard light environment. The results of this paper are expected to be applied for the acquisition of high-quality data.

Keywords: *Photometric Scanning, 3D Modeling, Variable Illumination Conditions, CloudCompare, VisualSFM*

1. Introduction

Currently, 3D modeling is being acquired through various scanning methods. Particularly, 3D data has been increasingly utilized due to the rapid development of 3D sensors and the spread of 3D printers. Generally, the 3D modeling data of a real object is obtained by laser scanning and depth camera [1, 2]. In this method, a laser light generated by the scanner is projected toward the object, and the time difference in which the laser is reflected according to the curvature of the object is used to estimate the geometry of the object. Although it requires expensive equipment, it is possible to measure microscopic variations and precise scanning. Another method is to use a depth camera. It mainly uses infrared rays to measure the depth. A variety of application software is being released due to the popularization of depth cameras such as Microsoft Kinect [3], Occipital's Structure Sensor [4] and Intel® RealSense ™ Depth Camera D435 [5].

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However, these methods require a separate hardware system.

The photometric scanning method utilizes images from multiple viewpoints without a separate scanning device [6]. Due to its easy accessibility, recently photometric scanning application software has been released. However, the quality is different depending on the environment and the object characteristics, and is not generally high in quality by other means. Therefore, various studies are being conducted to improve the quality. As a related study to improve the quality, Hafeez et al. [7] used a specific pattern. Yiwei Zhang et al. [8] used different illumination directions with low-cost accessory, and Chia-Kai Yeh et al. [9] proposed a powerful colored light photometric stereo method. Therefore, we analyze the effect on the modeling quality obtained by Photometric Scanning according to illumination properties. To do this, we compare ground truth data with each 3D data acquired under the hard light and soft light environments. The composition of this paper is as follows. Chapter 2 explains photometric scanning, and Chapter 3 explains experimental methods. Chapter 4 shows the performance evaluation results of the modeling data according to the environment, and conclusions are given in Chapter 5.

2. Photometric Scanning

Photometric scanning is an image-based modeling method proposed in the 1990s. Compared to the typical 3D scanning methods such as CG modeling, laser scan, and depth camera modeling, it is simple and efficient. This method uses images acquired at various viewpoints using a camera and converts them into 3D point clouds images [10]. Figure 1 is a schematic diagram projected from a pair of stereo images onto world coordinates.

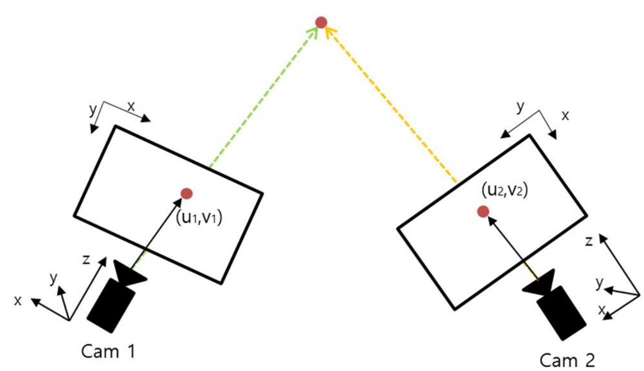
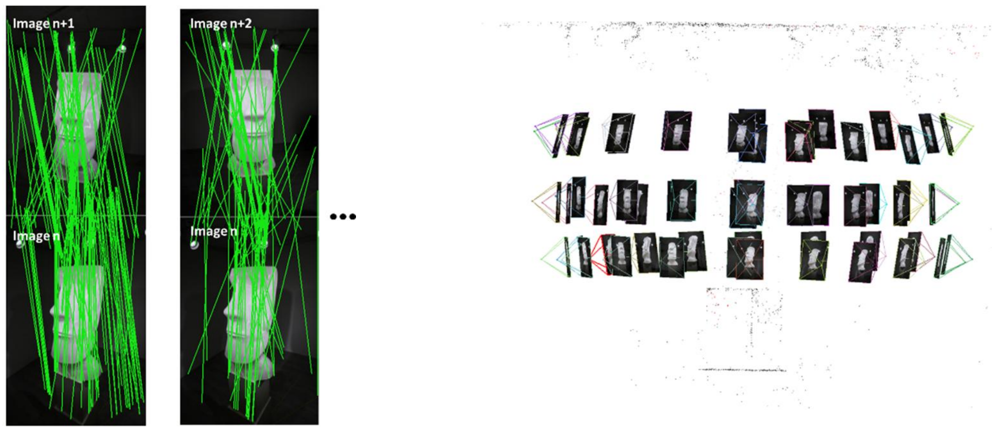


Figure 1. Schematic diagram projected from a stereo image onto world coordinates

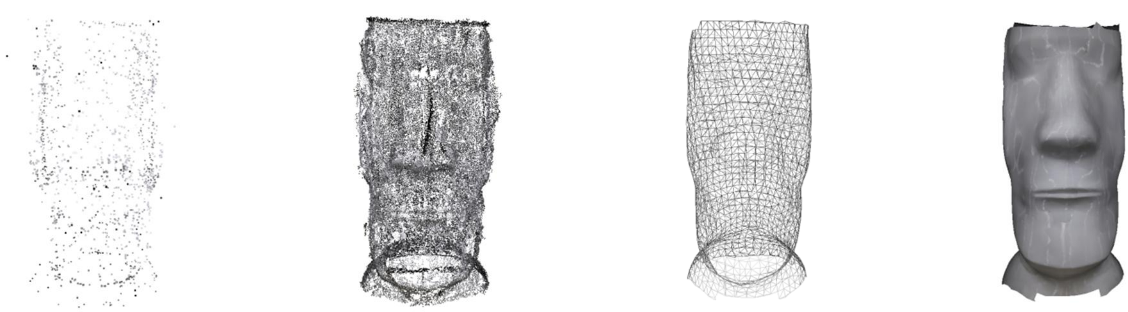
The general procedure for photometric scanning is as follows. First, a point is extracted in the world coordinates through the feature point matching between 2D images. A common algorithm for feature point matching is Scale Invariant Feature Transform (SIFT) [11]. This is robust to changes in size or rotation of the images or objects. SIFT has a step of attaching a descriptor to a key point, and a matching step of comparing a reference image with a target image using a descriptor. It finds feature points in the images of different scales. Each feature point defines a descriptor that contains direction and size information. Matching is performed by comparing the distance between the feature points of the reference image and the feature points of the target image. Matching points are precisely matched by separating inliers and outliers through a Hough transform. Finally, the least mean square is used to verify that the matching is correct. Second, the 3D structure is obtained by estimating the position and pose of the camera from the matching feature points between the images. Typically, SfM (Structure from Motion) is used, and Bundle Adjustment optimizes camera positions and 3D data [12-14]. Figure 2 (a) shows feature point matched using SIFT, and Figure 2 (b) shows 3D structure acquired with SfM.



(a) (b)

Figure 2. SfM (Structure from Motion)
(a) Matching feature points between the images
(b) Estimating the position and pose of the camera

The next step is to convert the sparse point cloud to a dense point cloud for the rigid structure. Generally, Patch-Based Multi-View Stereo (PMVS) or Clustering Views for Multi-view Stereo (CMVS) are used for this purpose[15]To transform the dense point cloud into a mesh, the Poisson algorithm is mainly used that generates a triangular mesh from the point clouds [16]. In the final step, mesh simplification and texture mapping is performed. Figure 2 shows the photometric scanning procedure while Figure 3 shows the 3D data acquisition process. Figure 3 (a) shows a sparse point cloud generated by the SfM and Figure 3 (b) shows the dense point cloud generated by the CMVS. Figure 3 (c) shows a mesh obtained from the point cloud using the Poisson algorithm. Figure 3 (d) shows the final textured mesh.



(a) (b) (c) (d)

Figure 3. 3D data acquisition process
(a) Sparse point clouds (b) Dense point clouds (c) From point clouds to mesh (d) Mesh with texture

3. Experimental method

3.1 Experiment procedure

The ground truth data used in this experiment is the source file of 'Moai' statue. To get the physical object, the Moai statue is printed using a 3D printer. The printed object is photographed using a consumer grade camera at various view-points. The 3D model generated from the images is compared with the ground truth and the quality is evaluated. Experiments are performed using open source algorithms. The software used are Visual SfM and Meshlab. Figure 4 shows the experimental procedure workflow. First, feature points extracted from images are matched through SIFT. We use the Bundle adjustment algorithm to estimate the camera position and pose, and obtain 3D structure as sparse point clouds. For rigid structure transformation, dense point clouds are obtained using CMVS. We acquire the mesh from the point clouds through the Poisson algorithm. The final 3D data (.obj, .mtl, .jpg) is obtained by mesh simplification and texture mapping. The simplified mesh is compared with the ground truth. To do this, we used CloudCompare software to compare and analyze the quality of the acquired data.

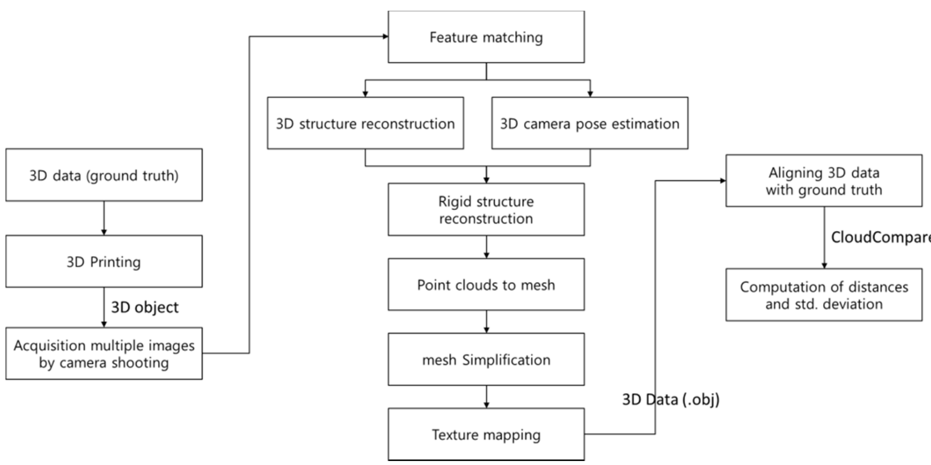


Figure 4. Flowchart of experiment procedure

3.2 Experimental environment

In this paper, we compared 3D modeling data obtained under the soft light and hard light environments with the ground truth to compare the results of illumination conditions. Figure 3 shows the experimental environment. Figure 4 (a) shows the ground truth 'Moai' statue used in this experiment. It was modeled in Rhino 3D software and printed using a 3D printer UNICORN (2500 mm (H) x 1500 mm (W) x 1500 mm (D)). The size of the object is 1,000 mm (H) x 600 mm (W) x 600 mm (D). Figure 4 (b) shows the markers drawn in the experimental environment which represents the camera positions. The camera is moved across 360° around the object to capture images at the intervals of 20° for each layer. The images are captured at upper, middle and lower layers and a total of 54 images were obtained. The resolution of all images in each data is 42 Megapixels. Figure 4 (c) shows the soft light environment. To maintain a uniform lighting environment, two lights are used for each of the four sides. Light are directed towards the white wall that bounces back on the object that creates a soft lighting environment. As shown in Figure 4 (d) lights are also directed on the object to illuminates the object. The lights used in this experiment are LED (PAR 30, 15 watt, daylight).

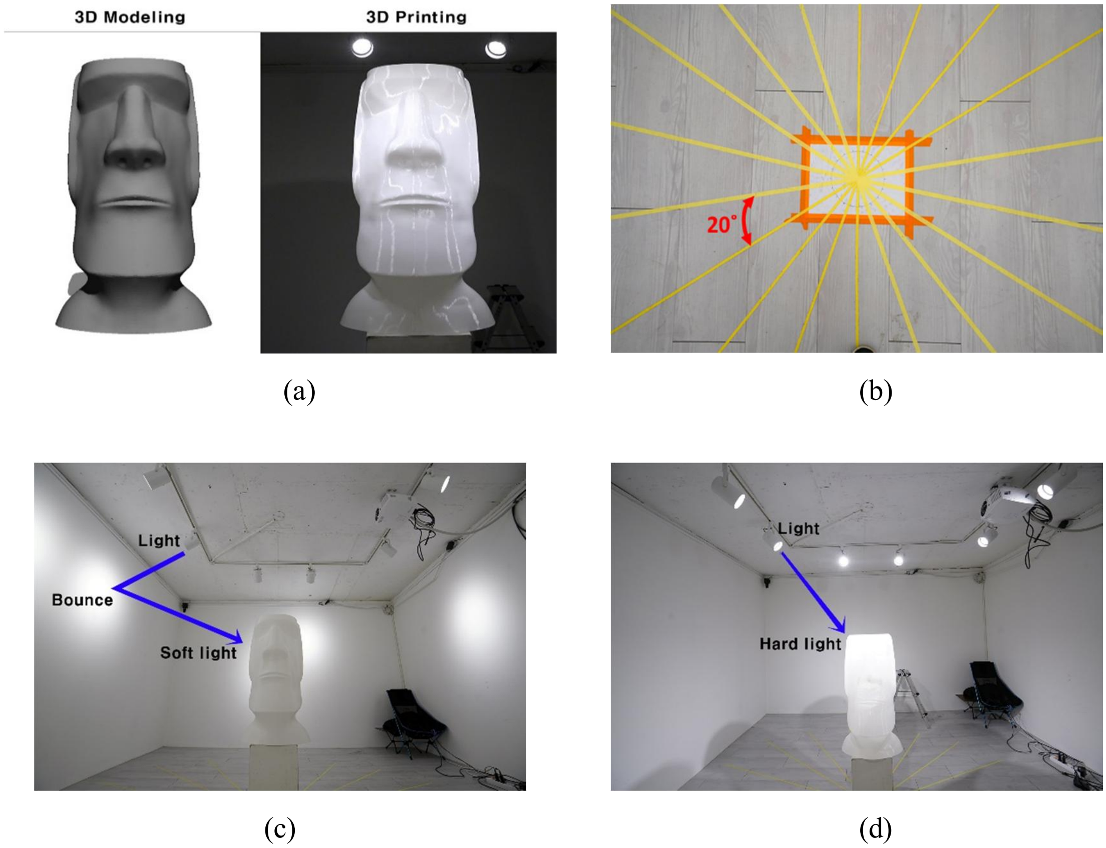


Figure 4. Experiment environment
(a) Ground truth & 3D printing object (b) Camera setting maker
(c) Soft lighting environment (d) Hard lighting environment

3.3 Performance evaluation method

To evaluate the performance of the methods, the image-based 3D models are compared with the ground truth data. The most commonly methods used for evaluation are ① Plane fitting, ② Profiling, ③ Cross Section, and ④ Point to Point comparison. The 'Plane fitting' methods compares the partial flat surface of the modeling data. In these methods, a plane is fitted to the surface of the generated model and the difference in the distance is calculated that is expressed as Std. Deviation (σ). The 'Profiling' method cuts a 3D model into sections and compares the edges of the sections extracted. This expresses the root mean square error (RMSE) of the difference between the edges distances of the two models. The 'Cross Section' method extracts the cross sections of a model and compares miss aligned parts of a specific area. It is useful to evaluate the structure of the modeling data. In 'Point to Point' method, the 3D models are registered with the ground truth and the difference between the points on the surface of 3D model and the ground truth is calculated which is expresses as Std. Deviation (σ). The following equation shows root mean square error.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2}$$

Here, $d_i$is the difference between the scanned data and the ground truth data. In this paper, we evaluated the 3D model using 'CloudCompare' [17]. This is a 3D point cloud processing software, which uses the 'Point to Point' evaluation model. The 3D models generated with the images taken under the soft and 3D model with the hard light are used to calculate the point cloud distance approximation to the ground truth as the standard deviation.

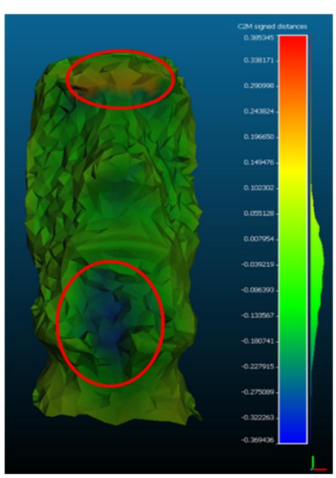
4. Results and discussion

In this paper, we compared the quality of photometric scanning according to the illumination conditions. Table 1 shows the numbers of vertices, mean distance, and standard deviation found for both models. For 3D modeling data obtained under the soft light conditions, the numbers of points in the point clouds are 2,252. For 3D modeling data obtained under the hard light conditions, the numbers of points in the point cloud are 16,838. The difference in mean distance from the ground truth is -0.058884 for the 3D modeling data obtained under the soft light condition, and -0.024232 for the 3D modeling data obtained under the hard light condition. Also, the difference in the distance from the ground truth is 0.090686 for the 3D modeling data obtained under the soft light condition and 0.039954 for the 3D modeling data obtained under the hard light condition.

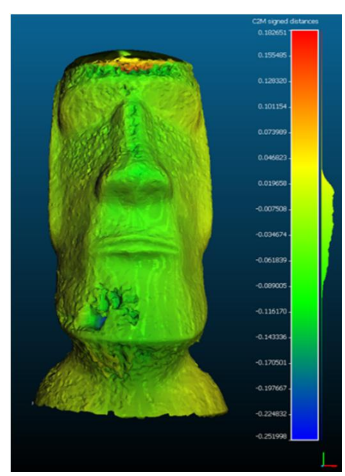
Table 1. Experiment results

Illumination Conditions	*Numbers of Vertices*	*Mean Distance*	*Std. Deviation*
Soft Light	2,252	-0.058884	0.090686
Hard Light	16,838	-0.024232	0.039954

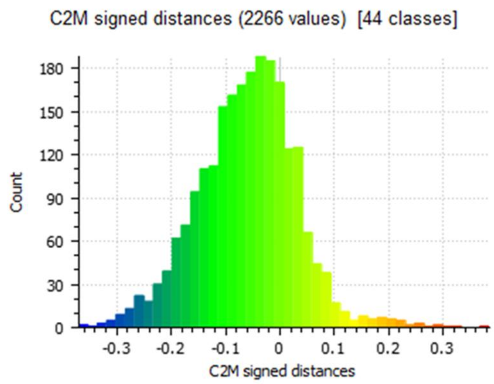
Figure 4 (a) and (b) show the heatmap representation and Figures 4 (c) and (d) show the histogram. Here, the blue region is that the three-dimensional model surface lies below the ground truth. Here, the red region is the three-dimensional model. It can be confirmed that the 3D modeling data obtained under the soft light condition has many portions (red, blue) where the distance value is greatly deviated from the ground truth.



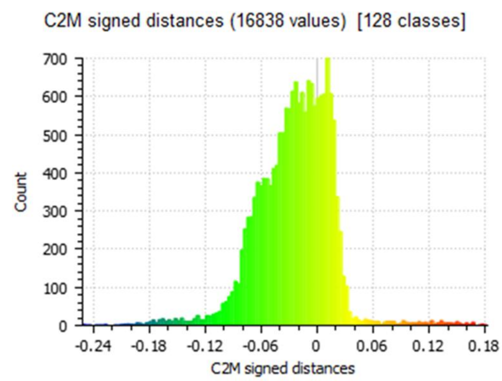
(a)



(b)



(c)



(d)

Figure 5. Experiment results with heatmap and histogram
(a) Heatmap representation with 3D model under soft light condition
(b) Heatmap representation with 3D model under hard light condition
(c) Histogram with 3D model under soft light condition
(d) Histogram with 3D model under hard light condition

The 3D modeling data in corresponding to soft light environment has relatively few less points in the point clouds. Therefore, it is unnatural to generate rough accurate modeling data. This is because the number of feature points extracted using the Scale-Invariant Features (SIFT) algorithm is insufficient. 3D modeling data in the hard light environment has more vertices in the point cloud and minimized standard deviation. It is judged that the images in hard light environment are well matched because the textures are well represented. Since the significance of the difference in the light quality of this experiment is shown, it is important to express the material of the object in order to acquire the feature point.

5. Conclusion

In this study, we studied photometric scanning method to obtain 3D data of real objects. This is more accessible and efficient than the methods required for scanning equipment. However, 3D data quality is lower than other methods. It also has a quality deviation depending on the image acquisition environment conditions. Therefore, various methods are proposed for obtaining high quality data. In this study, the quality of photometric scanning according to illumination properties was compared and analyzed. As a result, 3D data quality in hard light condition was better than soft light condition. This proves that this is due to feature point matching between images according to the material representation of the object. In order to acquire high quality 3D data by photometric scanning, it is necessary to study for high-quality feature point matching. Therefore, further study is needed by combining with various methods in objects with various properties.

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