AUTOMATIC RECONSTRUCTION FOR SMALL ARCHEOLOGY BASED ON CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT:

The paper present one approach to reconstruct the small object based on close-range photogrammetry. The goal is to generate the DSM (Digital Surface Model) of the object fast with high accuracy. Because close-range object have more distortion, occlusion, complex shape and surface. So the procedure is difficult to be standardized as aerial photogrammetry. In the sequences of steps (calibration, orientation, measurement, modelling), new algorithms and approach are applied to improve automation. Rotate platform can improve the controllability of photograph; planar scene calibration using 2D-DLT and bundle adjustment can improve the automation of calibration and orientation; A region segmentation algorithm based on color quantify is used to recognize the object region; multi-view matching in the constraint of 3D-TIN can generate the dense and reliable surface points automatically. The result demonstrates the improved approach is applicable and effective for 3D reconstruction of small object with sufficient texture.

1. INTRODUCTION

3D reconstruction for small archaeology has great significance in the research and protection of ancient cultural heritages. The paper mainly aims at reconstruction of one skull fossil over one million years old. For 3D reconstruction of the small object, it includes two important issues: One is measurement of surface, which can be used as reliable and quantified data for research. Second is texture mapping for the surface, which can provide photorealistic 3D model for exhibition. So accurate measurement and photorealistic surface model are expectation of reconstruction.

There are many approaches for measure object surface. With the development of techniques, laser scanning and photogrammetry are two main approach most widely used and available in contrast to other complex and expensive approach.

Laser scanning can directly obtain object’s surface with high accuracy. The data process mainly concentrates on cloud alignment and mapping texture. These two steps are difficult to be automatic. Especially for texture mapping, high resolution image need to be captured by camera, because synchronized image captured by laser scanner are low resolution normally. The images mapping to the surface generated by point cloud is very laboured, because these images are independent completely to point cloud.

With increase of the performance of the digital camera and development of the technology of calibration, close-range photogrammetry is more easily applied to recover 3D model of object with high accuracy. The recovery of objects’ model usually needs the whole surface of model. In order to ensure not only the precision of the intersection , but also the continuity of the feature of the images， multiple stereo pairs with short baselines are applied. The Corresponding 2D points in the sequential images, determines 3D-coordinates of the object points by the intersection computation. Image matching makes the measure process more accurately and quickly.

The construction process based on close-range photogrammetry can be devided mainly to orientation 、 measurement 、 modelling. So automation of construction depends on automation of these procedures. In the aerial photogrammetry, a series of data process flow has been industrialized. But for close-range, it can not be realized normally because of more complex scene, occlusion, distortion, and object’s various shapes.

In order to overcome these difficulties, a series of corresponding approach are implemented in the paper.

Firstly is a rotate table platform are used here as device for photographing. With the controllable device, photographing is more easily and accurate. 2) To improve calibration automation, the calibration based on planar grid is adopted. With automatic extraction of grid cross as control points and bundle adjustment, calibration and exterior parameters solve can be realized very well. 3) A segmentation approach based on color region are applied. It can recognize the object region in the image. So most non-object points can be removed, the automatic measured points can be used to generate the surface of object without manually edit. 4)3D TIN is used as DSM of the object, because close-range object are mostly need to be presented as true 3D surface. On the contrary, for aerial photogrammetry, 2D TIN can present the DSM of terrain well. 5) Multi-view match based on collinear constraint is used to generate DSM. The match process is coarse to fine in the constraint of TIN. It can contribute to generate dense and reliable points.

These improved automatic procedures can reconstruct the skull fossil with good texture in the experiment effectively; also can be applicable to similar small object.

2. CALIBRATION AND PARAMETERS SOLVE

2.1 Planar scene calibration

For high accuracy it is necessary in close-range photogrammetry to account for the variation of intrinsic parameters and its lens distortion. So self-calibration is required. Calibration using 3D control filed is reliable and high accuracy. But it is costly and is not suitable for spot calibration. So for non-metric camera, accurate method and flexible control scene should be considered together. In this paper, a flexible planar-scene camera calibration technique is applied. The method is proposed and implemented by Zhang.Y.J in 2003. Before it, Zhang. Z.Y put forward a camera calibration technique for planar scenes based on the orthonormal property of the rotation matrix , and precision of about 0. 35 pixel is obtained[1]

2.2 Planar Grid Calibration Based on 2D-DLT

Based on the planar scene, Zhang Y.J used 2D-DLT and collinearity equations to realize self-calibration[2]. The method mainly includes: 1) extraction of planar grid cross automatically and correspondence. 2) 2D-DLT (Eq.1) parameters solve and initial value decomposition of intrinsic and exterior parameters of camera. 3) Bundle adjustment to refine the camera parameters.

$$x = \frac{h_1 X + h_2 Y + h_3}{h_7 X + h_8 Y + 1} \qquad y = \frac{h_4 X + h_5 Y + h_6}{h_7 X + h_8 Y + 1} \tag{1}$$

where x, y = image coordinates
X, Y = planar coordinates of control point
$h_1,\ldots,h_8$ = DLT parameters

Consider the Critical Motion Sequences (CMS), it will make 2D-DLT parameters among images are linearly correlated in the case of images taken with a fixed camera while the planar grid is rotating around its *Z*-axis. When photographing for calibration, camera is hold in hand, and takes 4 pictures from 4 different orientations as Figure 1.

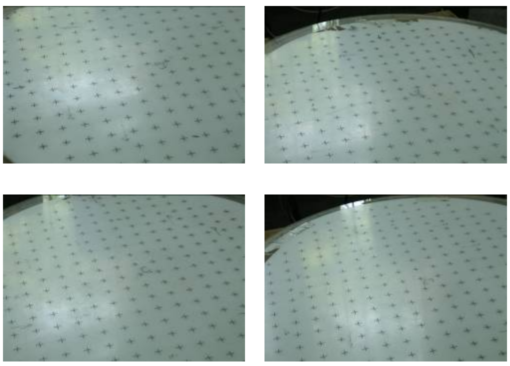


Figure1. Calibration Image (taken from four different views approximately at interval 90 degree)

2.3 Object Photograph and Exterior Parameters Solve

The rotate platform here can provide fitful photograph's view conveniently. It can provide exact even interval angle with magnetic stepping motor. It can ensure enough large intersect angle, and limit distortion of different view to a certain extent.

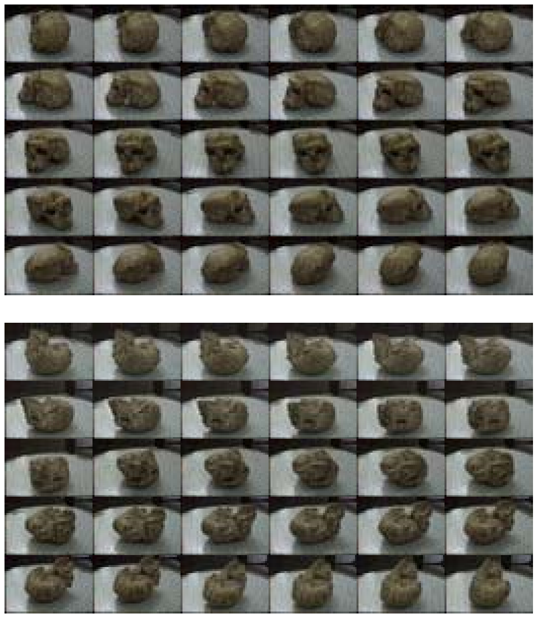


Figure2. Object's sequence images photographed.

As figure 2, for shoot the whole surface of object, the skull are placed with two pose. The surface points to be measured are composed of two parts, which have the relation of space similarity transformation. The transformation calculation is implemented after the exterior parameters are solved. The homonymous space points (at least 3 points) for solving 7 transformation parameters are determined by manually.

Calibration process can work out the exterior parameters as well as internal parameters. So the photos' exterior parameters for photo with object (skull here) to be measured are solved by the method. The only difference is the camera's intrinsic parameters are known value. So the exterior parameters' initial value is calculated by 2D-DLT, and optimal value is solved by bundle adjustment.

3. OBJECT REGION SEGMENTATION

The object's image region is just one part in the image range, which it is a difference between close-range photogrammetry and aerial photogrammetry. And it increase difficulty for automatic process for close-range photogrammetry.

Feature point extraction is implemented to generate points to be matched as the surface of object. These non-object points should be removed for get right surface of skull. To get the object region automatically, an approach based on color divergence for segmentation of the image was applied. This approach is proposed and implemented in the trees segmentation and reconstruction by Sheng Q.H[3].

Firstly input images, which are normally presented by RGB format, are converted to LUV color space because it meets human's psychophysical property of vision better. A perceptual color image quantization algorithm[4] is implemented. LUV color image was quantized to color map image. Then the resulted index class map was used to calculate divergence of color, and texture was analyzed by multi-resolution, and a region growing method was exploited to form the initial segmented regions. Finally over-segmented regions were merged according to the statistical Laws texture energy of each region.

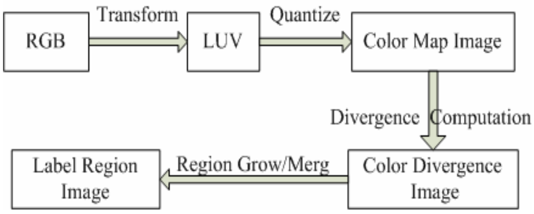


Figure 4. Steps of object region segmentation based on color divergence Computation

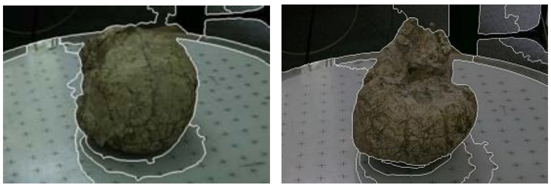


Figure. 5 Two example of object region segmentation

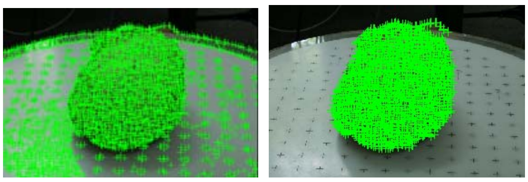


Figure 6. Removal of non-object points according to segmentation

The process low of segmentation is shown as Figure.4. The region segmentation results of two images of skull are shown as Figure 5. Main object region (skull) can be segmented from background (rotation table). Some small non-object regions that have similar texture also are segmented as object. However, because the object to be measured covers the most central region in the image, it is easy to determine the object region. So points in the object region can be kept to generate DSM as Figure 6. Although the segmentation result is not very fitting to the true object region which are segmented manually, this result is acceptable and functional. Because in the subsequent matching procedure non-object feature points are very likely to be miss-matched in the condition of geometrical constrains.

4. DSM GENERATION BASED ON TIN CONSTRAINT

4.1 3D-TIN

In the reconstruction of terrain, DEM is most common used model for terrain as a 2.5D presentation. For most objects with whole visual facade, true 3D presentation is required. TIN (Triangular Irregular Network) as non-parameterized presentation, is used widely because of its effective and compact. 3D-Delaunay mesh generation for unstructured points is researched widely. For surface points generated by photogrammetry, every space point has its source property of image, so it implicates visibility constraint. This is analyzed by Zheng S.Y[5] .On the base of initial Delaunay TIN, he proposed a new method of using the visibility information of feature points in images to refine the initial 3 dimensional model, and thus get the actual surface model of object. Here the algorithm and software are used to generate the TIN shown as Figure 7.

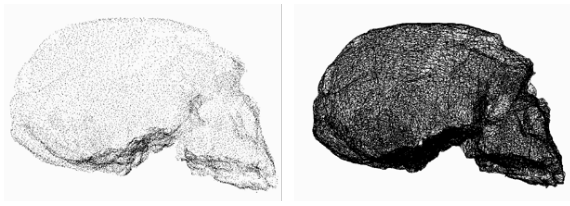
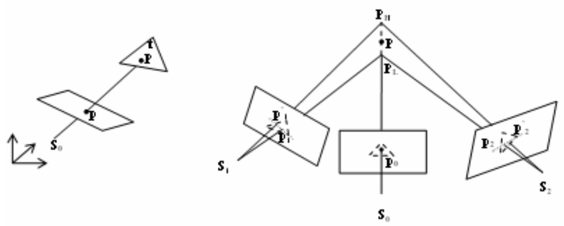


Figure7. Point cloud and 3D TIN model

4.2 Multi-view Matching based on collinear constraint

With the interior and exterior orientation parameters, 3D coordinates of space point can be measured by forward intersection computation. However the intersection angle is small because of the baseline is short between the stereo images. Multi-view intersection can increase the intersection angle and ensure the accuracy of intersection.



(a) (b)

Figure8. Multi-view Matching based on collinear constraint

Figure8 (a) illustrate that one space point determined by intersection by one ray and one triangle of coarse surface. The ray line is one from project centre to image point. (b) illustrate that how to refine the space point by match in the collinear condition constrained. The spatial line segment (P_L-P_H)is the spatial search range. Determination of obtain optimal spatial point depend on how to determine correct projective image point in the search process. Here we compute the mean of correlation coefficient(MCC) of the p_0 with two projective image point p_1、 p_2. P with the maximum MCC is considered as the matched space point [6]. This is the process of multi-view matching based on collinear constraint.

Key issue of Area Based Matching mainly is how to choose suitable searching strategy and matching parameters concerning. Matching window size, search window size and determination method of candidate matched point will influence the last result of matching. Normally coarse to fine strategy is used to promote matching reliability and accuracy. Furthermore, sparse to dense strategy is adopted. Firstly sparse feature points are extracted with high interesting value in large grid in the object region. In this step, search range is large and matching need to be implemented in pyramid. It spends much more computation time relatively. But the space points matched have high reliability. Then with initial TIN surface composed of sparse point, dense points can be matched in not only constraint of collinear but also constraint of initial TIN. Because of geometric constraint, the dense matching is more fast.

5. EXPERIMENT RESULT

5.1 Camera Calibration Result

The Camera used is Canon EOS 5D, which the pixel size is 4368*2912, the calibration's result is shown as Table.1 and Table 2.

	focus	x0	y0
Estimates	11567.04	2194.53	1446.33
RMS error	0.401	0.150	0.190

Table 1. Camera Intrinsic Parameters (Unit: pixel)

	$K1/10^{-9}$	$K2 /10^{-16}$	$P1/10^{-8}$	$P2/10^{-6}$
Estimates	2.5203	-1.0705	4.2548	-1.1595
RMS error	0.1378	0.2101	0.5710	0.1891

Table 2. Distortion parameters

5.2 Bundle Adjustment Result

The bundle adjustment is implemented, and the control point's error is shown as Table3, it includes two parts.

Part	Control Point Number	RMS of Image Observation (mm)	Distance RMS
Up Part	240	0.00567	0.149
Bottom Part	237	0.00637	0.148

Table3. Control Point Precision

The image point's residue is below 1 pixel. The measure precision can reach below 0.2mm.

5.3 3D Model

The 3D model of skull fossil with texture is visualized by OpenGL as Figure10. The model is composed of 27,863 points and 52,316 trianlges.

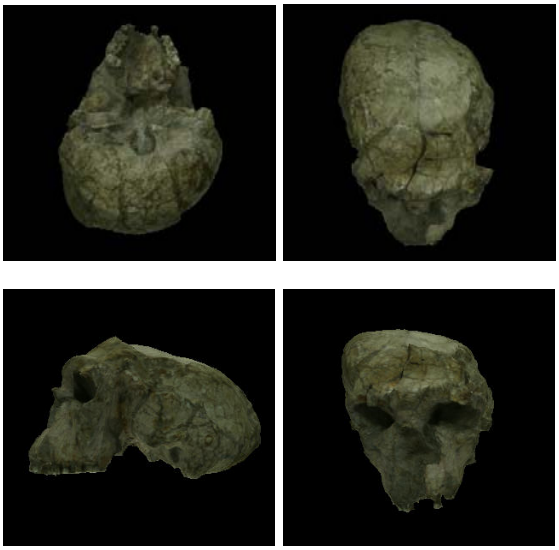


Figure10. 3D Model of skull fossil

6. CONCLUSION

To overcome the difficulty of reconstruction for close-range object, the paper addresses a series of improved methods to corresponding procedure. The experiment result demonstrates that these approaches are effective and applicable to small object with efficient texture. However, there are so many complex objects with different shape that control device should be more flexible. Robust line extraction and match should be applied to reconstruction for objects with line structures.

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