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A Paradigm to Create Free-Form Surface Modeling using Photogrammetric Reconstruction

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ABSTRSCT:

In today's scenario, a number of reconstruction methods are used for the modeling and preservation of various artworks. The creation of free-form realistic models is the most difficult aspects of 3D modeling and is not possible with input-output based parametric software's. Image based reconstruction is convenient way to surface modeling of free-form surfaces. In this work, the digital images are processed in open source software 'Meshroom' which follows photogrammetric reconstruction to generate point cloud of the object. The point cloud is further processed for CAD surface modeling using Poisson and Ball pivoting algorithms. The surface quality of the reconstructed surface and processing time are affected by several control parameters of these methods. The probability of holes in the surface generated in Ball pivoting method is more as compared to Poisson surface reconstruction.

KEYWORDS: Free-from surface modeling, Photogrammetry, CAD/CAM.

INTRODUCTION

3D reconstruction has great significance in the field of computer graphics, computer vision, animation, virtual reality, medicine, gaming, robotics, etc. The technological inventions in CAD/CAM provide a number of methods and techniques for design and manufacturing of various complex free-form surfaces. In today scenario, to obtain geometric data of object, 3D reconstruction techniques have been widely used for surface reconstruction and preservation of various artworks.

Sculpturing is an artwork of producing decorative surface, which represents 3D or 2D shapes of objects. In this work, the free-form physical models representing a person, idea, thing, etc., are carved using hand/mechanical tools on a surface of materials such as stone, clay, wood, or metals. The artists use additive and subtractive procedures to construct free-standing models, utilizing the materiality of the raw materials in the process. The geometry of object is evolved step by step on the planer/non-planner surface to the desired shape and size of the sculpture.

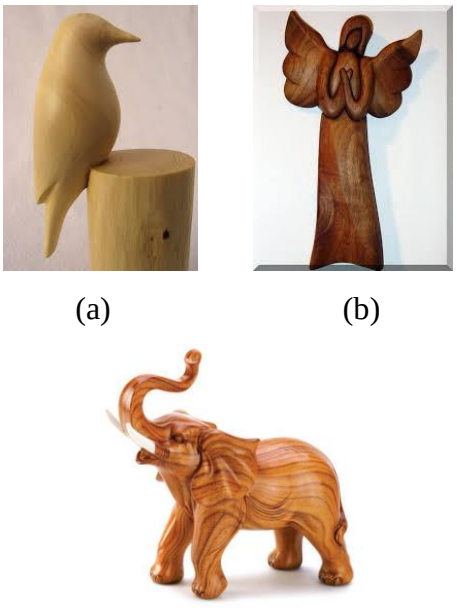
The creation of free-form realistic models is the most difficult aspects of 3D modeling and is not possible with input-output based parametric software's. The reconstruction of sculptured objects is not a common task and requires high crafting skills. As the craft people are leaving their work due to market competition with machine made product, so there is requirement of integrating CAD/CAM for modeling as well in recreation. Recently the use of reverse engineering is also fast paced for 3D modeling of existing objects and 3D reconstruction is most widely used technique in this field.

This work is towards the development of effective and low-cost technologies for 3D reconstruction of monuments for preservation as well for reproduction. This work presents a comparison of the viability of surface reconstruction through point cloud processing in a professional tool. The point cloud is created using photogrammetric reconstruction.

TRADITIONAL SCULPTURES

Traditionally, sculptures are reliefs or free-standing objects representing both visual and fine art produced by processing of hard or soft materials into three-dimensional objects. The sculpturing is the art or practice of shaping figures or designs on planner or non-planner surface by carving, modeling or casting which can found in cultures across the world. The word 'sculpt' represents the workmanship of shaping or carving of moldable materials to generate a shape of object. The skilled craftsmen's in this work are called sculptors.

Sculptures, on the basis of presence of feature details, can be classified as low, medium, or high detail sculptures. In low detail sculpturing, the geometry is slightly elevated from a background level with little or no border undercutting and few details present the shape. High detail sculpture contains fine features and looks realistic. The features in this type of sculpture represent the whole details and can be called as replica of object or structure. The high relief sculpting requires extremely high-level designing and carving skills as it have very fine details. The presence and projection of features in medium detail sculpture lies in between low and high detail sculpture, and is sometimes referred to as mid-relief. The carving artwork in Ajanta and Ellora Caves in India present high and medium details sculptures.



(a) (b)

(c)

Figure 1: Wooden sculptures (a) Low detail (b) Medium detail (c) High detail

RELATED WORK

Implementation of computer-aided design (CAD) for 3D modeling of art and craft objects is useful in terms of ensuring the quality and improving the level of artist [1]. The CAD modeling of sculptured surfaces with conventional design systems is quite difficult due their geometric complexity [2]. 3D reconstruction provides alternative a way to digitize and manipulate the existing sculptured objects and employed for modeling of wide variety of objects such as statues, pottery objects, archaeological sites, sculptures, etc. [3-6]. In order to employ reverse engineering for creation of sculptures, significant research is carried out for developing robust methods to digitize sculptures. Computer graphics is a key technology for the manipulation/transformation of sculptural model.

Over the last several years, 3D digitizing and modeling techniques have advanced significantly. In recent years, 3D imaging devices for the capturing of three-dimensional (3D) geometries have generated a lot of interest for a wide range of applications [7-9]. In digitization/3D reconstruction, there is no single completely automated approach applicable to all types of scenarios. Photogrammetry is a subset of image-based modelling, which includes methods like shape from shading, silhouette, and texture recognition [10-11]. In this approach, low-cost hardware can also be used for data acquisition and open source modeling tools also provide good results [12].

Using this photogrammetric method, a 3D model of the object or structure is recovered from the images taken from ordinary camera or smart phone. The literature shows that it possible for even the most novice user to create a wide range of objects from 2D images [13-14]. The Agisoft, 3DF Zephyr, Reality Capture, Blender, OpenMVG/OpenMVS, Colmap, and Meshroom are major professional software for photogrammetric reconstruction [15-16]. However, in such rebuilt 3D models, key minor details, such as the folds of the garment and other important edges, are left out or missing [17]. The metric accuracy in certain applications, such as 3-D modeling of cultural heritage, range sensor can also be employed to generate short range maps with fine details [18-21].

The point cloud data contains outlier and noise and a numbers of algorithms are available in the literature for cleaning [22-25]. Meshlab is open-source program and have all capabilities required for 3D modeling such as cleaning of point cloud, simplification and surface modeling [26-28]. Delaunay triangulation, Voronoi, Poisson, Ball Pivoting and Screen Poisson are major approaches for surface reconstruction available in point cloud processing tools [29].

PHOTOGRAMMETRY

Photogrammetry is a method of generating point cloud data by recovering geometric information of the physical objects from a set of images. To be more descriptive, photographs taken under well defined environments may be used to generate measurement data in three dimensions (X,Y,Z). Structure from motion algorithm is responsible for the magic of photogrammetry which interprets sequence of images to generate spatial data based on similarities in information between the images.

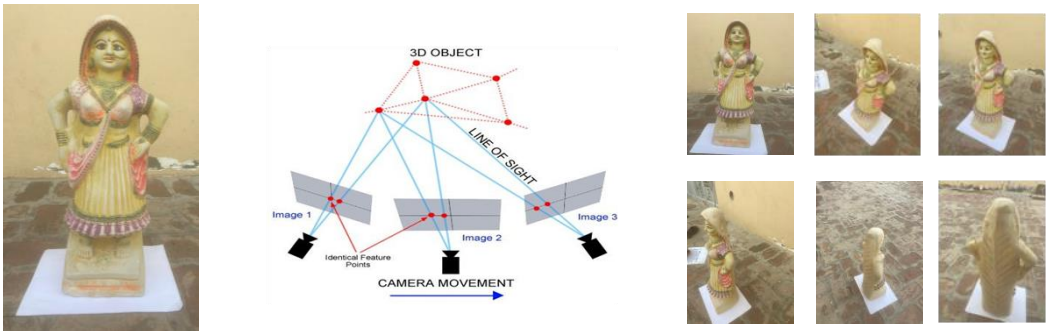
In current work, photogrammetry method is used to generate 3D shape of small sculptured objects. For this, a number of images of object are captured from different perspectives with the help of digital camera and

processed in Meshroom to generate 3D point cloud data. The main advantages of photogrammetry are its accuracy, speed of data acquiring and cost is effective.

DATA ACQUISITION

In the Photogrammetry, 2D images are fundamental source for three-dimensional geometric reconstruction. In general, images are captured using cameras, terrestrial sensors, satellite, drones, etc. for photogrammetric applications. All aspects of related to the environment set must be taken into consideration while capturing images, including the scale of the scene and the materials and textures used. It has a significant impact on the final mesh quality.

Image capturing is major part of data acquisition in photogrammetry, in which set of images are captured from different angles moving around 360 degree of object. External light source can be used to improve lighting condition and reduces shadow effect. While capturing images, motion blur and depth blur can cause distortion in images, so care should be taken.



Physical model Capturing Images from different views Captured images

Figure 2: Capturing Images for photogrammetric reconstruction of sculptured object

PHOTOGRAMMETRIC PROCESSING

In this work, open-source photogrammetry software 'Meshroom' is employed to generate 3D geometry of model from a collection of unorganized photos [30-31]. Meshroom is a node-based framework for processing different computer vision tasks and enables the users to configure the different pipelines in order to utilize them for specific requirement. Dense scene is prepared on basis of depth map of images to produce point cloud data.

For reconstruction process, set of images of object are processed in Meshroom workspace as shown in Figure 3. Left side workspace is for the loading images, middle show selected image view and right hand side present processing of images set based of SfM. After loading the image set in workspace, a series of processes in node based network is defined to carry out the 3D reconstruction based on photogrammtery. The first step is to generate feature points by processing the 2D images and these points refer to 3D points on object surface. All the images are subjected to feature detection. The feature matching in the series of steps, process all the points to find positions in 3D space generated using nearest neighbor search. Structure from motion calculates the position of different feature points by utilizing the camera parameters. The value of process parameter of node

related to matching, mesh filtering, texturing etc. is defined according to the feature details. Meshroom generate the point cloud data in .obj format by following the node framework parameters.

PRE-PROCESSING

The presence of noise and outlier data in point cloud is major problem in image based reconstruction methods. So for an accurate CAD modeling, cleaning of point cloud data is necessary. The cleaning procedure also reduces the polygonal mesh, lowering the computing power required to render the object.

In this work, Meshlab is employed for processing of point cloud data for accurate CAD modeling. Cleaning of point cloud data is first step which removes a compact faces, merge close vertices, removes duplicate faces and vertices, and a specific object can be extracted from a complex scan. The mesh models have also holes in some places due to cleaning or missing data. Repairing of mesh data is also employed to for hole filing, simplification and feature preservation.

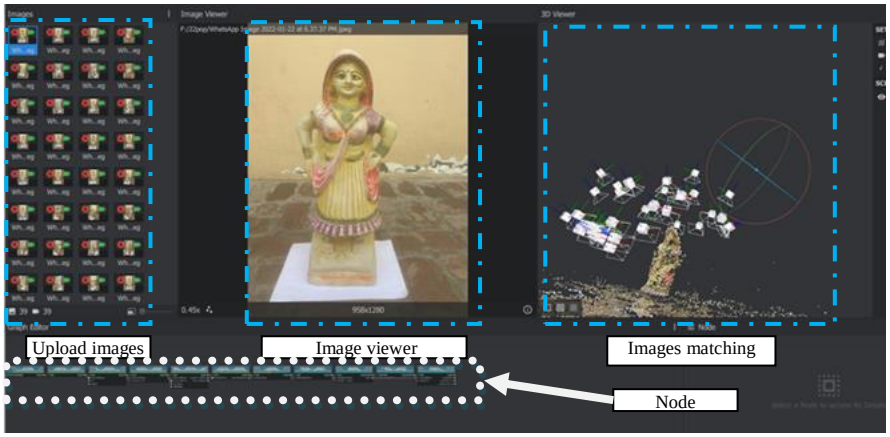
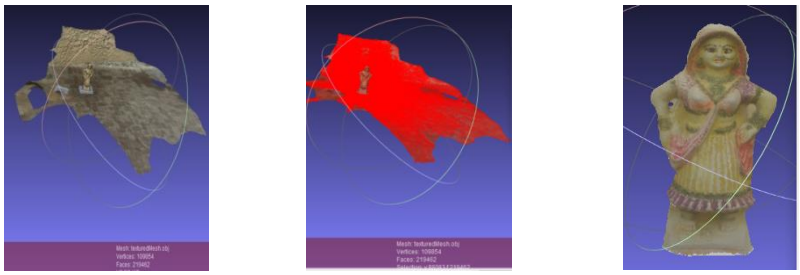


Figure 3: Photogrammetric reconstruction in Meshroom workspace



(a) (b) (c)

Figure 4: Basic pre-processing (a) Raw Point cloud (b) outlier removal (c) simplified model

In the mesh processing, the decimation is used to simplify the complex mesh structure by reducing the number of triangular meshes whereas, the interpolation is utilized for preservation of features lost during simplification. Using the features such preserve boundary, preserve topology and preserve normal tries to do not affect mesh structure during simplification. Quality threshold parameter is used for filtering bed shaped faces and it works good for value between 0.2-0.3.

SURFACE RECONSTRUCTION

To represent the object shape, a CAD surface geometry is constructed from simplified mesh using a surface reconstruction method. After the pre-processing, surface reconstruction method is required to generate CAD surface model from simplified mesh. In this work, two surface reconstruction methods, Poisson surface reconstruction and Ball pivoting, are employed and compared for quality and time taken in processing. In both methods, a layer of watertight surfaces is created from oriented point sets surrounding the object.

Poisson Surface Reconstruction : Poisson surface reconstruction is optimization based method for creating surface from scanned data of the object. In this method, the point cloud data is sampled with normal's and a approximation indicator function is solved for gradient matching. A triangular mesh is reconstructed from a pair of oriented 3D points. In Poisson surface reconstruction, there are number of parameters that may be altered to influence the result of the surface generation process. These parameters have an impact on the point selection, accuracy of the reconstruction and processing time in execution. The major factors are octree depth, solver divide, sample per node and surface off set parameters.

The parameters influencing the Poisson reconstruction process was varied in reference each other which effect number of vertices and faces in surface model as shown in Table 1. The influence of the aforementioned factors on the surface creation process was investigated as shown in table 1 via the use of the reconstruction quality and processing time for the created surfaces as shown in figure 5. Octree depth is one of the most critical factors which is used to hold the rebuilt object's 3D surface mesh and its value lies between 4-15. Processing time will increase with increase in value of octree depth and mesh resolution improves exponentially with octree depth. A value of 6 is found most effective with respect to processing time and number of faces. The number of points given to each octree by the matching cubes method is referred to as the samples per node. The value of samples per node tested for value between 1-20 and in this case value 2 is provide good results. Solver divide specifies the gradient value to solve the poisson equation and generally used between 4 to 15. The result in table shows that after value of 6, it does not affect surface geometry. Surface offset parameter serves as a threshold correction value and used for internal offset (<1) or external offset (>1).

Table 1: Effect of processing parameter in Poisson surface reconstruction

Points	Model	Octree depth	Solver divide	Sample per node	Surface offset	Vertices	Number of Faces	Timming in msec
50000	Model 1	6	4	1	0.5	4009	8022	1115
	Model 2	8	6	2	1	56834	113684	16605
	Model 3	10	8	4	1.5	57472	130859	15341
100000	Model 4	6	4	1	0.5	3426	6852	937
	Model 5	8	6	2	1	3466	6932	1223
	Model 6	10	8	4	1.5	3520	6830	1439
150000	Model 7	6	4	1	0.5	172	340	132
	Model 8	8	6	2	1	121708	60851	18336
	Model 9	10	8	4	1.5	13948	67349	20357
200000	Model 10	6	4	1	0.5	3470	6940	928
	Model 11	8	6	2	1	3472	6944	1174
	Model 12	10	8	4	1.5	3450	6952	1184

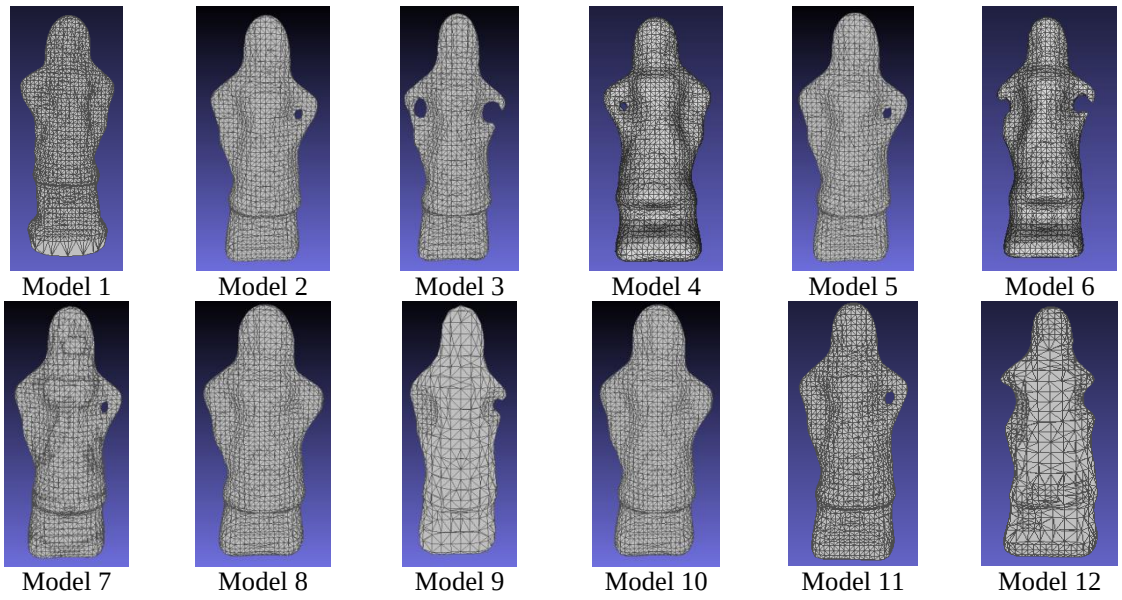


Fig. 5: Mesh generated for different value of octree depth, solver divide, sample per node and surface offset presented in Table 1.

Ball-pivoting surface reconstruction: Another effective approach of surface reconstruction is the ball pivoting algorithm (BPA) [32]. In this algorithm, a ball radius is used for construction of triangular mesh structure. As the ball moves through the cloud, three-dimensional meshes are produced that connect the three-dimensional points. After pivoting from the edges of existing triangles, the algorithm pivots again and again until it reaches three spots where the ball does not fall through, at which point a new triangle is created. The process is repeated until the entire cloud of points is connected by a triangle. Ball radius, cluster radius and threshold angle are affecting parameters in this surface reconstruction.

Ball radius is the most significant BPA parameter and represent the radius of the ball (ρ) which pivots (rolls) across the set of points in consideration. The change in ball radius (generally taken in % average distance between points) has a significant impact on the algorithm's performance for filling up gap between faces. For small free-form surfaces, the values of ball radius between 0.5 to 1 provide acceptable results. To reduce or merge small triangles in mesh, cluster radius is used as a filter and a value of 20 give good results. The angle threshold specifies the maximum allowed angle between that new edge and the active edge.

Table 2: Effect of processing parameter in Ball pivoting surface reconstruction

Points	Model	Ball radius %	Cluster radius %	Angle threshold in degree	Number of Faces	Timing msec
200000	Model 1	1	20	90	171215	8393
	Model 2	1.5	10	90	335267	81514
	Model 3	0.5	10	90	352170	11151
	Model 4	2	20	90	31125	7238
	Model 5	1	30	90	79958	6568
	Model 6	0.5	20	90	352170	11230

Model 7	3	20	60	19079	2360
Model 8	1	5	90	343841	42026
Model 9	0.5	30	75	351907	10945
Model 10	2	10	90	164679	18251
Model 11	1	30	90	19904	4426
Model 12	2	10	60	341632	37811

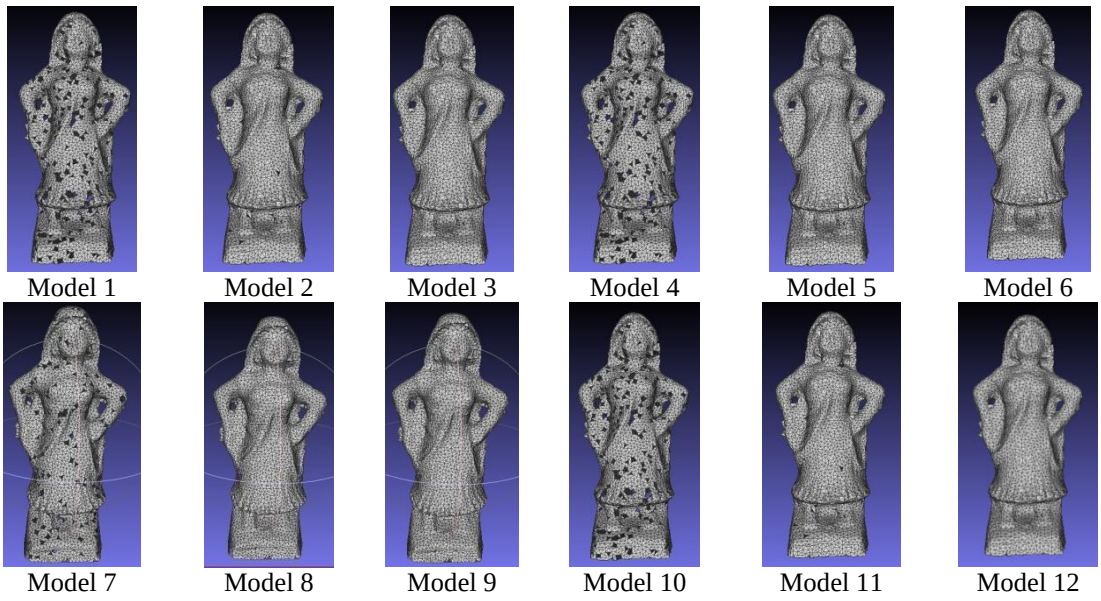
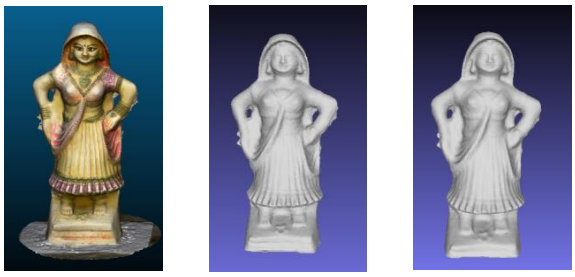


Fig. 6: Mesh generated for different value of ball radius, cluster radius and Angle threshold in degree presented in Table 2.

CONCLUSION

For the craftsman, working with traditional sculpting methods, it is very tedious task to create and replicate complex sculptured surfaces. Free-form surface modeling relies heavily on method of object reconstruction. In this work, photogrammetry is used for 3D reconstruction using which is based on image processing technology and provide good results. The reconstruction process performed automatically with the help of a sophisticated matching approach. This work presented surface modeling using Poisson and Ball pivoting algorithms and effects of different parameters on quality of surface as shown in figure 7. 3D reconstruction accuracy is profoundly influenced by noise and undefined holes in the reconstructed surface. For the reconstruction quality and processing time, experimental results shows that the Poisson reconstruction most accurate and generate robust 3D surface models. The limitation of reconstruction based on photogrammetry is time utilized processing and sensitivity to resolution of image required for reconstruction.



(a) (b) (c)

Figure 7: Free-form surfaces modeled (a) Point data model (b) using Poisson algorithm (c) using Ball pivoting algorithm.

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