DETAIL-PRESERVATION
3-D MODELLING FOR ELABORATE BUDDHA SCULPTURE

Zhiqiang Du, Tingsong Wang*, Guanghui Liu

State Key Laboratory of Information Engineering in Surveying Mapping and Remote Sensing, Wuhan University, 129 Luo Yu Road, Wuhan, Hubei, 430072, P. R. China-
duzhiqiang@lmars.whu.edu.cn, wts_paul@yahoo.com.cn, lgodh2007@163.com

KEY WORDS: Detail Based Data Acquiring, 3-D Modeling, Integrated Registration, Scan Alignment, Detail Replacing

ABSTRACT:

The elaborate sculpture of Buddha owns its specific characteristics like plenty of tiny, deep notches and large stretches of flat parts. Thus, a single consideration of each side will cause different problems in acquiring and reconstruction. For instance, one solution aiming at all those notches may lead to redundancy in flat parts and inefficiency, while the opposite is sure to lose a large number of details. In order to present its original appearance and details efficiently, a novel workflow is brought forward, mainly including the application of Laser Scanning technology, multi-precision data processing. This workflow which generally contains four steps, that is Detail Based Data Acquiring, Point Cloud Aligning, Point Cloud Re-sampling, Detail Replacing, has been applied in the Skamania statue and other Buddha statues 3D model reconstruction project, proving that it is an efficient, low-cost and useful method to rebuild high precision 3D models and reconstruction of digital cultural heritage.

1. INTRODUCTION

In Mogao Caves, Dun Huang, Gan Su, China, there are many mural paintings describing the story of Buddhism, like Skamania who founded Buddhism, coming from India. In Chi Lin Nunnery, Hong Kong, there are many elaborate Buddha sculptures. As time goes on, the statues will suffer damage from natural erosion, human activity and ineffective protection, a lot of human civilization will be lost. As we know, it is inefficient, high-cost to sculpt an elaborate Buddha statue by hand. Fortunately, in recent years, the recording, modeling and visualization of Cultural Heritage is always an interesting issue for the Scientific Community (IEEE, CIPA, VAST, Eurographics, EPOCH EU, ICOMOS, ISPRS) (Gonzalez-Aguilera, 2009), including data acquiring techniques, 3D modeling techniques. Because of the development of scientific technology, today we can easily acquire 3D points that contain more details of the physical objects, reconstruct digital 3D model. Therefore, we can protect it permanently through establishing digital document in the computer.

Model reconstruction from points scanned on existing physical objects is of great importance in a variety of situations such as reverse engineering for mechanical products, computer vision and recovery of biological shapes form two-dimensional contours (Zhang, 2003). (Remondino, 2009; Paquet, 2008) introduce some methods to reconstruct complex physical objects, like castles, churches. (Li, 2008) introduces the whole process of building Digital Mogao Caves according to its own features. In (Remondino, 2009), 3D modeling can be either from reality (photogrammetry, surveying, laser scanning) or from computer graphic, CAAD or procedural methods. They are all suitable for large scenes. But Buddha is an independent object and owns specific characteristics like plenty of tiny, deep notches and large stretches of flat parts. Laser scanning technology can acquire large amount of points with high precision. However, a single consideration of each side will cause different problems in acquiring and reconstruction. For instance, one solution aiming at all those notches may lead to redundancy in flat parts and inefficiency, while the opposite is sure to lose a large number of details. So detail based data acquiring is introduced to overcome it according to object particularity. In order to present its original appearance and details efficiently, a novel modeling method is brought forward combined with our reconstruction practice, including: modeling with different precision separately, detail replacing. This method is proved to be efficient. The following sections will discuss it in detail, containing data acquiring, model reconstruction. The conclusion is provided in the last section.

2. DETAIL BASED DATA ACQUIRING

Original data directly affects the accuracy and efficiency of post-processing and the quality of its final 3D model. In recent years, the technology of laser scanning, as a new method for acquiring the 3D coordinates of objects in high speed, becomes the hotspot of attention. The speed, flexibility and high precision of the laser scanning system make the efficiency of surveying improved in a large degree (Liu, 2008). In our research, two new laser scanning system are used to get Skamania woodcarving point in high-speed, reliable and high precision, namely the Creaform's HandyScan^{TM} ExaScan and the Zoller+Fröhlich GmbH's Z+F IMAGER5006.

* Corresponding author. Tingsong Wang (wts_paul@yahoo.com.cn).

Different parts of Skamania have their specific characteristics, like head with plenty of tiny, deep notches and the body with large stretches of flat parts. One solution only aiming at those notches may lead to redundancy in flat parts and inefficiency, while the opposite is sure to lose a large number of details. Thus, detail based data acquiring method is brought forward, in which the original data is obtained with different precision according to its own characteristics. Our practice proves that it is a proper method both in speed and precision.

2.1 Planning

Before the data acquiring, a unity scanning planning was done, including scan resolution selecting, scan station setting and the distribution of reference targets. The distribution of details is taken as the key in this process.

Skamania statue has its own specific characteristics:

1. Plenty of tiny, deep notches and large stretches of flat parts
2. Large, elaborate sculpture, 900 mm × 900 mm × 1800 mm
3. Some notches is too deep to obtain data, like armpit
4. We can not acquire the whole data of left hand.

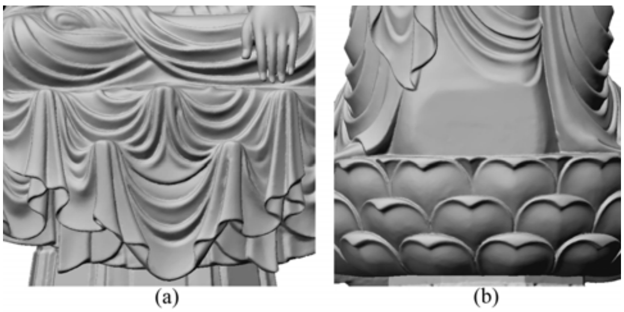

Figure 1. (a) is deep notches (b) is large stretches of flat parts.

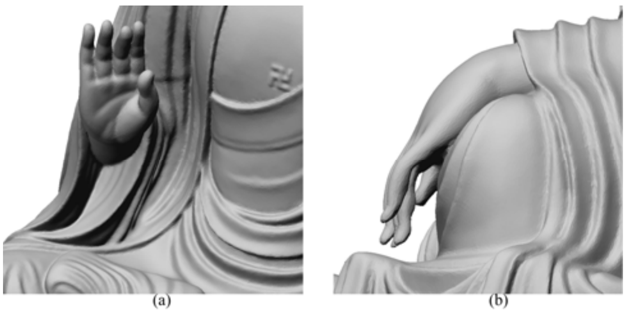

Figure 2. (a) is the armpit (b) is left hand.

Based on our practice and statue's characteristics, different scanning resolutions are designed for acquiring accurately and efficiently. Then the number of scan stations is calculated because the resolution is determined by the dimension of the voxel, which represents the base unit to acquire original point data.

The scanning system requires reference targets, whose density various from 20mm to 100mm, in order to self-determinate its own position on at least three targets. In order to keep the original appearance, reference targets are uniformly distributed, located in relatively flat area. And in the corner of statue, more targets should be affixed to the physical woodcarving sculpture for the purpose of acquiring data continually. During our experiment, we found that reference target net, made of targets and fishing net, though convenient in distributing, is actually vulnerable to human action and natural influence like wind. Therefore, we affix reference targets to the physical body surface, which is not permitted when scanning human cultural heritage.

2.2 Data Acquiring

After data acquisition planning, two main groups of point clouds is going to be acquired separately by HandyScan^{TM} ExaScan, namely low precision group (the utility, 24 scanning stations) and high precision one (the details, 8 scanning stations). For the utility scanning, a compared low precision is used, 500 × 500 × 500 mm with the basic unit of voxel of 0.98 mm, while a high one is adopted for the elaborate parts, 200 × 200 × 200 mm with the basic unit of voxel of 0.39 mm. In our case study, Imager5006 plays supporting role in Data Acquiring, obtaining data which HandyScan can not acquire, with middle low precision. For details, see (Achille, 2007) and the help documents. One of the key issues during scanning is to pay attention to the surface normal direction as it directly determines scanning speed as well as the data quality.

3. MODELLING METHOD

It is important that different modelling method is corresponding to different data resource, for example, the modelling method based on remote-sensing image and Light Detection And Ranging (LIDAR) is suitable for modelling large-range 3D city; vehicle-carried photogrammetry can apply to modelling 3D landscape beside of street; a single building or buildings are usually modelled by engineering survey, close-range photogrammetry, or laser scan on ground (Li, 2002).

In our practice, elaborate Buddha sculpture is selected, which owns its specific characteristics. In order to present its original appearance and details efficiently, point clouds of different precision are acquired. But in the existing commercial software, the original data sets cause failure of its reconstruction algorithms for different precision and uneven density of point clouds, e.g. more holes, rough surface. To overcome these problems, a corresponding novel method is brought forward combined with our reconstruction practice.

General speaking, this workflow contains four main steps like data acquiring, data pre-processing, model reconstruction and model optimization. But there are differences between the traditional modelling workflow and ours in following aspects:

1. We introduce digital sculpting technology to reconstruct elaborate 3D models for best preserving its details in high precision.
2. Our new method solves modelling problems of different precisions. Using the detail replacing method, realistic 3D model can be reconstructed from multi-precision point cloud on existing physical objects.
3. Based on the details and its distribution, the original data is acquired with different precision through HandyScan scanning system, which is a handheld one. During this process, plenty of scanning techniques are used based on its surface normal characteristics.

Thus, combined with our characteristics in the traditional process, a novel workflow can be summarized in figure 3 and each key step is expanded after it.

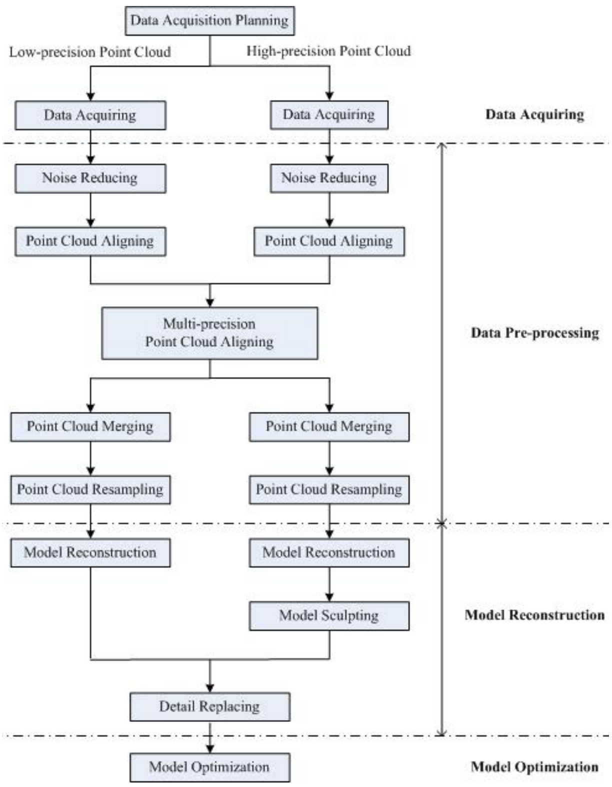

Figure 3. Detail based data acquiring and model reconstruction workflow, aiming at best preserving all the details in high precision in each step.

3.1 Aligning

The aligning of point cloud from different viewpoints turns to be a key challenge in reconstructing high-quality 3D scans as it always requires rigid attitude transformation. The final accuracy of a 3D model is function of the quality of the image registration process (Sturzenegger, 2009). In order to guarantee good quality in the scans registration, an overlap around 25% was preserved between adjacent scans (Gonzalez-Aguilera, 2009). In our case, a robust method named the feature based integrated registration is introduced. Based on at least three feature points interactively selected in each scan, the rough overall registration (Manual Registration) is complemented. Then the ICP method (Global Registration) is implemented to refine the registration in partial regions.

Multi-precision Point Cloud Aligning

Since the point clouds are acquired by HandyScan with different precisions, this difference between them must be taken into account when aligning the two groups. (Remondino, 2009) introduce something about registering and integrating all models created by different techniques like laser scanning, image-based modeling. To get a good result, multi-precision point cloud aligning is implemented. In one hand, relative special relationship between them is established. For another, those additional errors caused by human operation and software during data processing are prevented.

In the end, all the original data sets are in the same coordinate system, including the utility and the details. After Global Registration, standard deviation of error (SDE) is below 2 mm which fully satisfies the need of post processing.

3.2 Re-sampling

After point cloud aligning, there are many overlapped parts owning different densities in adjacent stations. When wrapping, point clouds of different precisions lead to the generation of spikes, more holes and rough surface. Thus, to different precision point cloud, re-sampling process based on distance and curvature priority is adopted separately in order to get a uniform density. Finally, we obtain the utility points and detail points separately, for example, in the Skamania processing, 2,085,702 utility points and 2,626,282 detail points are gained. And its corresponding effect in modeling is shown below.

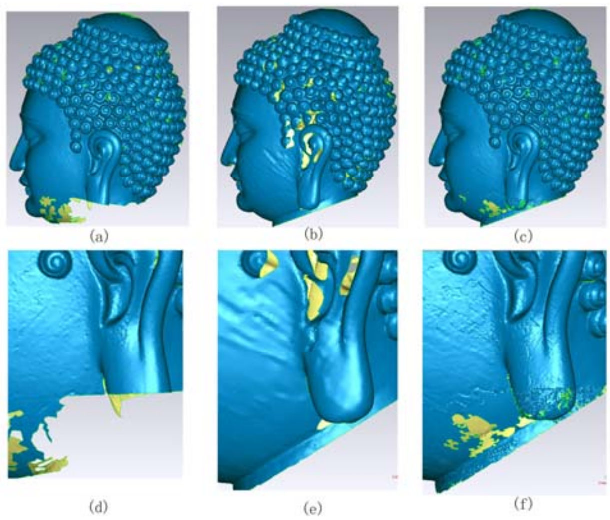

Figure 4. (a) High-precision model, 154 holes (b) Low-precision model, 78 holes (c) Model generated from multi-precision data without re-sampling, 156 holes. (d) (e) (f) show other problems like spikes and rough surface correspondingly.

3.3 Detail Replacing

It is a key issue to elaborate model reconstruction in our practice for detail preserving. Models of corresponding region from different precision, reconstructed separately, is not entirely coincident in the same coordinate system. In order to create realistic characters, the “detail preservation” method is presented, aiming at replacing low precision mesh with high one in the same region full of details, which mainly includes triangulation, edge selecting and region replacing process.

Triangulation

Based on the point cloud gained above, a robust and efficient triangulation algorithm named surface oriented reconstruction algorithm, is chosen to generate a fine triangular mesh, as it can best preserve the surface change and build its reasonable structure. Then, after hole filling, smoothing and decimating polygons, a utility model with its detail surfaces of Skamania statue is built up.

For the detail surfaces, Autodesk Mudbox 2009, a digital sculpting and texture painting software provided by Autodesk Inc, is adopted for covering the shortage of original data. Due to the measuring ability and equipment limit, some particular areas can not be gained since, like reference target parts, deep notches areas and dense detail regions. In order to present its original details, this powerful sculpt tool is used to build these details according to the outline gained from original data, like the hair of Skamania.

Edge Selecting

After triangulation, different precision meshes are gained. In order to best present the original geodetic characteristics, some parts with dense details in the utility model should be replaced by its corresponding high precision meshes. Considering the maximum of detail replacing and minimum of post-processing cost, some key rules is built up, namely in two aspects. Firstly, region covering, which means the boundary on the utility model, should be sketched according to the shape and scope of the high mesh. Secondly, flat area picks. As to avoid destroying the geometric details and control registration errors between utility model and the high precision mesh, the edge line should go through flat areas. Based on the principles above, the boundary line is selected by each facet on the utility model and these facets is deleted, thus its enclosed region is separated from the utility in topology for later detail replacing.

Detail Replacing

Though the utility model is separated in topology, but the low precision piece is still in the same object with the utility. Then, according the different topologic relationship, based on some domain algorithm, the low precision piece is deleted, after which its facets and points are deleted. Therefore, the utility model with an appropriate “hole” region and the high precision piece is left, and they hold a right relative position. So the only thing left is to merge them into a new object. After all these, an integrated model with dense details is gained.

But some post optimization is also needed to fill each facet holes on the boundary. Because there are small gaps in the elaborate 3D model after merging, several curvature based filling methods are implemented to repair the corresponding surrounding area. For example, filling holes has different strategies; one algorithm based on selecting edges of holes is applied to fill gaps in a polygon object. While you can also build one or more narrow bridges across a hole by defining edges of bridge in order to fill holes separately. After filling holes and model optimization such as smoothing, decimating polygons, the whole model of Skamania is obtained owning 2,959,764 facets of triangle. All this workflow and its result are shown in figure 5 vividly.

Figure 5 shows the whole process of Detail Replacing. After Multi-precision Point Cloud Aligning, the utility and the details are transformed to the same coordinate. The two groups, the utility and the details, are built separately. Then we get two independent polygon objects. Based on the relative space relations, select and delete the low precision mesh according to the high one’s range. Then merge the two polygon objects, fill holes. The digital elaborate 3D model is reconstructed.

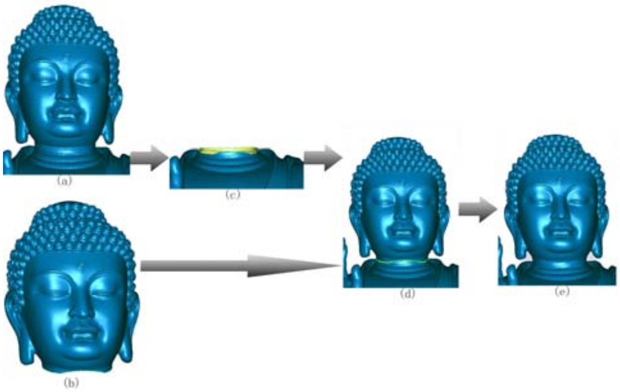

Figure 5. The process of Detail Replacing with the purpose of reconstructing elaborate 3D model from different precision point clouds. (a): low precision model. (b): the high precision model. (c): low precision model without head. (d): the merged model with gaps. (e): the final elaborate model.

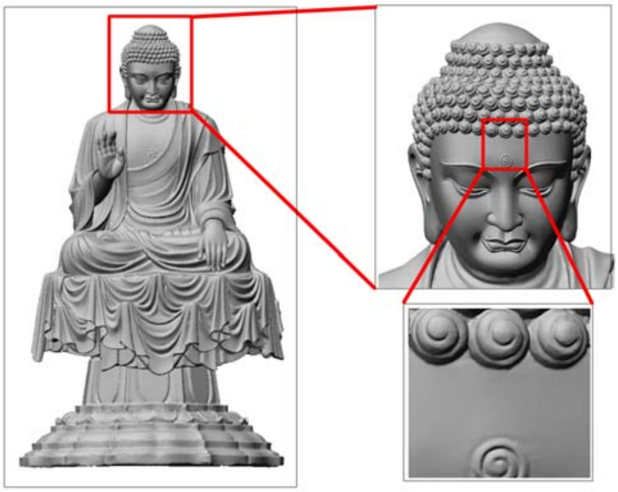

Figure 6. The elaborate model of Skamania and local details

Finally, after model optimization, the elaborate Buddha 3D model is reconstructed from different precision point clouds. Figure 6 shows the whole 3D model on the left after all this processing, and the right shows a local magnified result of detail replacing.

In the end of our modeling process, the holistic optimization is done for correcting geometric and topologic errors in tiny parts. Thus an intelligent decimating polygons method based on allowable deviation, is carried out to reduce the amount of triangles aiming at preserving features of model with less data. After Detail Replacing, relaxation is applied to eliminate the selected edge trace and make it more smoothed. While the digital sculpting technique can also be chosen to enhance the shape by sculpting its specific characteristics.

4. EXPERIMENT AND ANALYSIS

The Skamania statue, which is sculpted by hand within 2 years, is a relative large sculpture, 900mm*900mm*1800mm.

We implemented our modeling method by using Reverse engineering software, like Geomagic Studio 10, Rapidform XOR2, Polyworks 10, and the digital sculpting and texture painting software, Autodesk Mudbox 2009. It is running on a PC with Inter Core (TM) 2 @ 2.66 GHz processor and 2.0 GB memory. We spend 10 days to reconstruct Skamania model, including data acquiring and modeling.

In our case, 32 scanning stations are planned to finish the task of data acquiring, including 8 scanning stations with high precision (0.39mm) for the elaborate parts and 24 scanning stations with low precision (0.98mm) for utility scanning.

In this section, we present 3D reconstruction results obtained by our method. It is tested on multi-precision point clouds acquired by HandyScan scanning system, 0.39mm (8 stations) and 0.89mm (24 stations). Based on feature points interactively and ICP method automatically, all the points of different stations are transformed to the coordinate system of the first scanning station. After carrying out point cloud aligning, merging and re-sampling, for the utility, 2,085,702 points are remained and for the details, 2,626,282 points are left.

Then surface oriented reconstruction algorithm (Remondino, 2003) is implemented to reconstruct 3D model. For relatively flat, smooth region, we use filling holes method to deal with the lost data. For some area of tiny, deep notches, like the hair, digital engraving method is adopted to sculpt the details after filling holes. At this point, two model objects, the utility and details models are reconstructed separately. After detail replacing, the whole, elaborate model is built completely. For visualization and digital archiving, model optimization is carried out to optimize Skamania 3D elaborate model.

Finally, the outline of Skamania 3D model can be drawn on the computer screen in several display modes. For example, wireframe display mode which renders models using a wireframe representation describes only the edges in a transparent drawing, without texture or shading information. Smooth display mode renders models as smooth-shaded surface based on smooth shading algorithm and the surface normal of the surrounding faces are averaged and at each vertex is assigned a normal (Remondino, 2003). Point display mode which describes only the shaded 3D points draws point cloud models after processing like reducing noises, re-sampling.

Figure 7 shows the difference between high and low precision models. From figure 7, we can see high precision model well preserve his specific characters, his beautiful eyes and facial expression. For the woodcarving Buddha statue, our modeling method can well keep the original appearance.

After detail replacing, the selected edge is left because of different precision model (figure 8). Multi-precision model is built separately according to different precision data. Two models, the utility with high precision and the details with low precision, in the same region, can not coincide with each other, because both the precisions of original data and the parameters used to triangulation are different. The above problem can be solved by smoothing and/or sculpting.

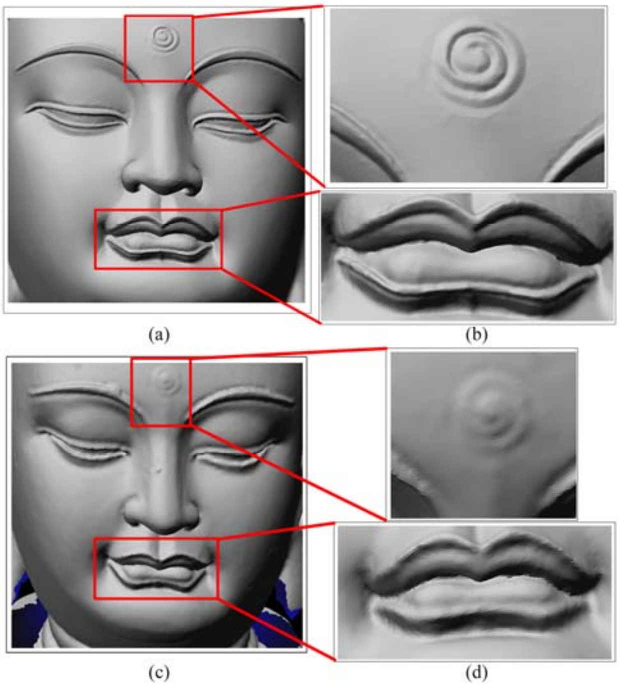

Figure 7. Different precision model: (a) is the model of high precision and (b) is its local magnified result, (c) and (d) are from low precision correspondingly.

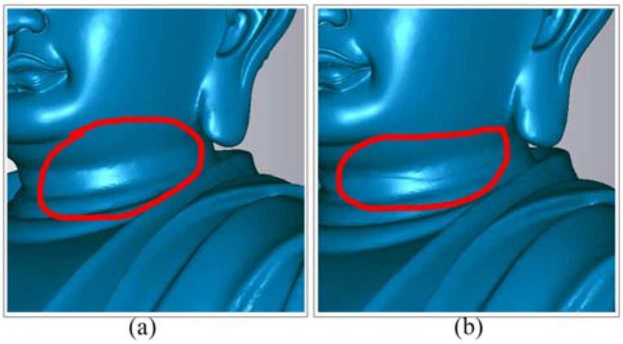

Figure 8. (a) is the model after post-processing, like smoothing, sculpting. (b) is the model without post-processing.

5. CONCLUSION

In this paper, a novel workflow for detail preserved scanning and 3D modeling is introduced, and it has been implemented successfully in the Skamania statue 3D reconstruction project. The main idea is that different precision model is built separately from various resolution point clouds and then detail replacing is implemented to get high precision geometric model. During modeling process, this method is proved to be simple, efficient. But there is disadvantage too: heavy workload of data acquiring. In our practice, many technologies are used to rebuild 3D model of Skamania statue efficiently, like Reverse Engineering, Laser Scanning and digital sculpting. A fine 3D digital model with more than 2 million facets for the sculpture, is gained, which perfectly preserves its original characteristics with the least triangles. At last, in order to satisfy high modeling and visualization demands, we also optimize the elaborate 3D model. The novel workflow is also successfully used to reconstruct other Buddha sculptures in the near future. So this digital documentation is surely significant in the future.

References

Achille, C., Brumana, R., Fassi, F., Fregonese, L., Monti, C., Taffurelli, L., Vio, E., 2007. Transportable 3D acquisition systems for cultural heritage, reverse engineering and rapid prototyping of the bronze lions of the saint isidoro chapel in the basilica of san Marco in Venice, *XXI International CIPA Symposium*, and Athens, Greece.

Gonzalez-Aguilera, D., Munoz, A. L., Lahoz, J. G., Herrero, J. S., Corchon, M. S., Garcia, E., 2009. Recording and modelling Paleolithic caves through laser scanning. In: *International Conference on Advanced Geographic Information Systems & Web Services*, pp. 19-26.

Li, D., Yang, J., Zhu, Y., 2002. Application of Computer Technique in the Reconstruction of Chinese Ancient Buildings. In: *International Archives of P&RS of the ISPRS commission V symposium*, Corfu, Greece, Vol. XXXIV, Part 5 Comm. V, pp. 404-406.

Li, D., Zhu, Y., Du, Z., 2008. From Digital Mogao Caves to Digital Chi Lin Nunnery. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Beijing, China, Vol. XXXVII. Part B5, pp. 981-986.

Liu, J., Zhang, J., Xu, J., 2008. Cultural Relic 3D Reconstruction from Digital Images and Laser Point Clouds, In: *Congress on Image and Signal Processing 2008*, Sanya, Hainan, China, Vol. 2, pp. 349-353.

Paquet, E., Beraldin, J.-A., Viktor, H. L., Benedetti, B., 2008. Computer aided reconstruction of complex sites and architectures: application to the grotta dei cervi and the broken frescoes of the Assisi basilica. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Beijing, China, Vol. XXXVII. Part B5, pp. 219-224.

Remondino, F., 2003. From point cloud to surface: the modelling and visualization problem. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Tarasp-Vulpera, Switzerland, Vol. XXXIV-5/W10.

Remondino, F., El-Hakim, S., Girardi, S., Rizzi, A., Benedetti, S., Gonzo, L., 2009. 3D virtual reconstruction and visualization of complex architectures-the "3D-ARCH" project. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Trento, Italy.

Sturzenegger, M., Stead, D., 2009. Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. *Engineering Geology*, 106(3-4), pp. 163-182.

Zhang, L., Zhou, R., Zhou, L., 2003. Model reconstruction from cloud data. *Journal of Materials Processing Technology*, 138 (1-3), pp. 494-498.