Research on 3D Digitization Scheme of Cultural Relics Preserved for a Long Time

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Abstract: With the development of digital technology, museums are facing a great challenge in the preservation and utilization of 3D data of cultural relics. Based on the demands on long-term preservation of 3D data of cultural relics by museums, a solution of 3D digitization of cultural relics is proposed in this paper for the unbalanced cost-efficiency-result, rare data utilization and inconsistent data storage scheme in the process of digitization. To solve the problem of unbalanced cost-efficiency-result, an evaluation model of 3D digitization has been designed by the Palace Museum, namely comprehensive "cost-efficiency-result" evaluation model. By adding a QR code control device for close range photogrammetry of cultural relics the high digitization cost, low digitization efficiency and inconsistent data quality are solved. Based on the specific needs of preservation and utilization, different grades are specified for 3D data of cultural relics, and a three-layer hierarchical structure and storage scheme is designed in this paper, which solves data inconsistence and difficult data sharing. The above methods have been widely used in the digitization project of the Palace Museum, and the related studies and practices also provide reference for the further development of national 3D digitization standards.

Keywords: Museum; Cultural Relics; 3D Data; Photogrammetry; Accuracy Control Conference Topics – Exploring the New Horizons; Building the Capacity & Capability

1.Introduction

The research and application of 3D reconstruction technology have been developed rapidly in recent years. With the emerging 3D digital resources of cultural relics, there is a great challenge in the long-term preservation of 3D digital resources of cultural relics [1].

Generally speaking, when it comes to the long-term preservation of 3D resources of cultural relics in museums, the first consideration is to use the most accurate data collection means and 3D data with the highest accuracy to digitally record the cultural relics for sustainable preservation as far as possible. However, in the practice, 3D digitization of cultural relics in museums is required to not only satisfy the needs of long-term preservation, but also assist to develop restoration, virtual repair and virtual display in the preservation of cultural relics. Therefore, for the long-term preservation of 3D data of cultural relics, both the quality of data and its long-term availability shall be ensured, of which the latter mainly refers to that the content of digitized data can be reused by interpretation [2]. 3D data of super high accuracy usually cannot be reused directly, so it is unrealistic to only consider long-term preservation without controlling the amount of data. In addition, few funds and a large number of cultural relics in museums shall be taken into consideration, and the special needs and difficulties of cultural relics shall be weighed, so as to promote 3D digitization of cultural relics in an orderly way.

However, at this stage, there is a quite serious phenomenon, where most organizations have no corresponding 3D data specification except for few with their own standards due to the different digitization collection technologies and processes of cultural relics adopted by various museum institutions of cultural relics at home and abroad. Non-uniform technical index requirements of digitization, inconsistent quality inspection and evaluation, and different operation methods and processes all lead to the uneven quality of 3D data of cultural relics in museums. Some 3D data can neither meet the requirements of long-term utilization, nor meet the needs of digital preservation and service. The root cause of the above problems lies in the fact that most institutions are unable to weigh the relationships among cost, efficiency and result at this stage.

Based on the fundamental needs of long-term preservation of cultural relics data, and on the premise of ensuring the safety of cultural relics, the relationships among efficiency, cost and result quality shall be weighed; common problems related to 3D data of cultural relics at present are analyzed; and the 3D digitization scheme of cultural relics applied by the Palace Museum, including collection and storage, shall be shared according to the actual situation in the field of cultural relics.

2. Overview

More and more museums begin to use 3D digitization technology to record the digital information of cultural relics, and use 3D data to carry out the research of cultural relics.

3D reconstruction technology of multi-view image is used by Zhangjiajie Museum to carry out 3D reconstruction to bronze Buddha of Ming dynasty. Through validation analysis, the geometric error of the 3D model is about 0.2mm, and the color and texture information of bronze Buddha is restored, disease situation is clear and visible, and information records of cultural relics of Zhangjiajie Museum are enriched simultaneously [3]. Operation method combining photogrammetry with total station is used in 3D data collection process of ancient relic, the Dayan Pagoda [4]. Compared with traditional photogrammetry, this method has the characteristics of more accurate data, and 3D information of cultural relics can be obtained more quickly and more accurately through the algorithm optimization. Liu Xiao and Wu Xunwei studied 3D computer reconstruction and display of the damaged antiquities, and used the 3D computer cultural relic restoration program to repair the Shuangyang Bottle, so that the 3D digitization technology of cultural relics can be used for the cause of cultural relic protection better [5].

Aimed at Castulo, an archaeological site of Roman architecture in Spain, researchers record 3D data through photogrammetry technology to obtain a virtual model of Roman cornice, and use 3D printing technology for application of non-invasive restoration [6]. In the pilot project of “marching towards virtual museum - 3D digitization of class-A objects selected from the collections of the Archaeological Museum of Zagreb”, the 3D digitization method for cultural relics of different sizes and materials is studied, laser scanning technology is used to generate 3D models of cultural relics, and the results are used for virtual reconstruction and fabrication of reproduction[7]. Professor Tanaka’s team of Ritsumeikan University in Japan scanned a boat shaped floating object named Fune-hoko by laser, and used point cloud data to fabricate reproduction and carry out 3D visualization restoration[8]. Different from traditional computer animation, they calculated the edge data of the model by extracting the 3D model data features, so that more information can be simulated, such as structural features, structural mechanics and assembly process. In University of the Philippines-Diliman, the use of photogrammetry technology for 3D reconstruction of museum or indoor exhibits is studied, photos taken by the digital SLR camera and mobile phone are used to create the model, and the virtual reality environment of the University Museum is created [9].

To sum up, 3D digitization technology is used by various museum institutions of cultural relics at home and abroad to research and protect cultural relics, and there are many research results. However, due to the different starting time of 3D data collection of cultural relics, different collection methods and lack of unified business process standards, the related problems caused are numerous and intractable. For example, to collect 3D data of cultural relics with high quality, some institutions cause problems of high cost and low efficiency; to control the collection cost and improve the collection efficiency, some institutions cause the problem of low quality of 3D data of cultural relics, and the data cannot meet the needs of preservation and service; some institutions do not have a unified standard and process, thus causing the instability of 3D data quality of cultural relics; and different data standards and formats among institutions make it difficult to share data.

It can be concluded from the above problems that the long-term preservation of 3D data of cultural relics of museums has more characteristics and difficulties when compared with the general data preservation, which need more consideration in the field of museum of cultural relics. The first is the quality of 3D data. Different from 2D image recording, 3D digitization of cultural relics can record 3D information of cultural relics in an all-round and high-accuracy way. The 3D data of cultural relics are very meaningful for expert research, cultural relic protection and data preservation. Only high-quality 3D data can be valuable for sustainable preservation. The second is data utilization. High-quality 3D data often faces a huge amount of data. For preservation, we really need higher data quality, but for reuse of 3D data, we often need to reprocess the data to make it meet the data conditions of cultural relic restoration, virtual restoration and virtual display. Data simply pursuing the accuracy and ignoring the reusability is not qualified. The third is the efficiency of 3D digitization. The number of cultural relics is huge, and 3D digitization is usually inefficient. At the same time, the higher the data quality needs more time on digitization. Therefore, to carry out 3D digitization preservation to cultural relics better and more comprehensively, it is very important to improve work efficiency. The fourth is the cost of 3D digitization. Problems of few funds and personnel are common in the field of museum of cultural relics. To preserve more data for a long time, we must reasonably control funds of 3D digitization of each cultural relic. The fifth is data sharing. Long-term preservation is bound to face data sharing. From collection to processing to data utilization, the data we retain is huge and diverse. Choosing reasonable data for preservation and having unified standards among institutions are the key to future data preservation and sharing.

3. Method Research

To solve the above problem, with the help of the experience and practice of 3D digitization of cultural relics collected, and based on the "cost-benefit" principle [10], the Palace Museum designs an evaluation model of 3D digitization for cultural relics in museums - comprehensive "cost-efficiency-result" evaluation model, and uses this model to evaluate several commonly used 3D digitization methods. On this basis, we summarize a new method - a new method of accuracy control of 3D data of cultural relics based on photogrammetry, and this method can well balance the relationship among cost, efficiency and result. We also classify and store the high-accuracy 3D data of cultural relics obtained according to the actual situation. This method is introduced in five parts below.

3.1 Comprehensive "cost-efficiency-result" evaluation model

The Palace Museum has the largest and best preserved wooden structure palace complex in the world, and has more than 1.86 million precious cultural relics in the fields of ancient calligraphy and painting, ancient artifacts, palace relics and book archives [11]. The Research Institute of Digitization Application of Cultural Assets of the Palace Museum, established in October 2003, is aimed to apply advanced digitization technology to protect, research and display the precious human cultural heritage of the Palace Museum [12]. In the past two decades, with the continuous popularization of 3D technology, in addition to the conventional use of cameras to record the image of cultural relics, importance has gradually been attached to the 3D data of cultural relics. 3D image can display the original features of cultural relics more intuitively and accurately, convenient to the development of research, display, restoration, identification, cultural creation and other work of museum collections [13].

The Research Institute of Digitization Application of Cultural Assets of the Palace Museum has studied 3D data collection and processing methods of cultural relics for many years. Technical means combining 3D scanning with photogrammetry is used, 3D data collection of cultural relics collected is being carried out quantitatively year by year, and some relevant industry standards have been formed. Through years of practice, we find that the cost, efficiency and result of 3D digitization are very important.

Most museum institutions of cultural relics have a very large number of cultural relics. To steadily realize the 3D digitization preservation of cultural relics, except for a few extremely important cultural relics, the collection time of each cultural relic is very limited. In the limited time, it is difficult for us to define, measure, analyze and improve the 3D data of each cultural relic, and we cannot repeatedly collect and test the data of the same cultural relic, so we urgently need to improve the collection efficiency [14].

Museum is a place to protect cultural heritage, having very precious cultural resources, and these cultural resources are non-renewable. Because the cultural heritage can be recorded and reproduced by 3D digitization technology comprehensively and truly, and the 3D data of cultural relics can provide the possibility for the sustainable preservation of cultural relics, in the field of museum, to make the data be preserved for a long time, we have very high requirements for the 3D data quality of cultural relics. The 3D data quality of cultural relics needs to rely on the evaluation of data collectors, data custodians and data consumers - collectively called 3C [10]. The collector carries out the evaluation to the data collected, including the evaluation of color, structure, range and data volume; custodians carry out the evaluation based on the differences between the 3D data generated and the original cultural relics; the evaluation of data consumers on whether data can be used reasonably. Only the data meeting the requirements of the three conditions can be called high-quality data. High-quality data plays the most important role in the long-term preservation of 3D digitization of cultural relics.

The “cost-benefit” principle is adopted in general project management, which is a method to evaluate the project value by comparing the total cost and benefit of the project. As an economic decision method, cost-benefit analysis applies cost expense analysis method to the planning decision, to find out how to obtain the maximum profit with the minimum cost in the investment decision[10]. To comprehensively consider and discuss the long-term preservation needs of 3D digitization of cultural relics at the present stage and find the balance point, we introduce this principle into the 3D digitization of cultural relics in museums, and design a comprehensive “cost-efficiency-result” evaluation model. Based on this evaluation model, 3D digitization is evaluated in an all-round way from the cost, efficiency and result, so as to choose the method with relatively low cost, relatively high efficiency and relatively high result quality.

3.2 Evaluation of 3D digitalization methods Preparing

Under this evaluation mode, several common acquisition methods of 3D digital data are compared by the Palace Museum, and experiments are conducted to analyze the relationship among cost, efficiency and results, and to weigh the advantages and disadvantages of each data acquisition method. At present, 3D data collection of cultural relics is mainly finished with photogrammetry and laser scanning. The 3D data generated by these two methods have their own advantages and disadvantages, so the two methods can be used independently or combined with each other.

Table 1 Evaluation of several common 3D digitalization methods

Method	Cost	Efficiency	Result
Laser scanning	High equipment cost Low personnel cost	High	Grid model of high precision Texture mapping of low precision
Photogra-mmetry	Low equipment cost Low personnel cost	High	Grid model of low precision Texture mapping of high precision
Combination of laser scanning and photogra-mmetry	High equipment cost High personnel cost	Low	Grid model of high precision Texture mapping of high precision

3.2.1 Laser scanning

When collecting 3D data with laser scanning method, 3D laser scanner shall be to obtain massive point cloud data on the surface of objects through contactless intensive scanning of cultural relics, and the data obtain can be computed for the 3D model of cultural relics. Laser scanning technology has the characteristics of no contact, fast speed and high precision of model generation [15], but the high-precision laser scanning equipment is expensive, so the cost of this method is high. The efficiency of 3D reconstruction is high as laser scanning can be used to obtain the 3D information of cultural relics in real time. However, laser scanning cannot obtain the color information of cultural relics, and the model mapping can only be finished by matching the cultural relic photos and models, so the accuracy of the mapping data is relatively unstable and the accuracy is low due to the large number of artificial intervention and the different experiences of producers. Therefore, 3D data obtained by laser scanning has the characteristics of high precision of model geometry and low mapping accuracy, and it is widely used for the geometry collection of cultural relics or the production of replicas.

3.2.2 Photogrammetry

Photogrammetry data acquisition is to collect 3D objects in all directions through one or more image acquisition equipment, and photos shall be taken on multiple circular orbits around cultural relics. Then, 3D spatial geometric calculation shall be conducted on photos by computer to generate 3D models with textures. This method has lower equipment cost, simpler manual training and less manual intervention in later data calculation, so the cost is lower.In this method, the reconstruction efficiency is high; the acquisition time is short; and the later data mainly depends on computer calculation. The data accuracy is mainly affected by the number of collected photos and the setting of the later calculation software. The model generated can directly obtain the geometry and textures. The data obtained by this method is less interposed by humans, so it can avoid the data precision which is not easy to control due to the different levels of artificial technology in the later stage. The error of the texture is smaller than that of manual mapping as the texture and model generated are calculated directly. However, the disadvantages of this approach are also obvious. Because the 3D reconstruction data is generated from the 3D space of photos, only 3D scale of the model can be obtained, rather than the exact size of the cultural relics. Generally, the size data is obtained by the method of fitting the dimension measured by manual and the later model. Therefore, although the texture is more accurate, the error of 3D data geometry is slightly larger.

3.2.3 Combination of laser scanning and photogrammetry

In order to improve the accuracy of data, laser scanning data and photogrammetry are used together for the 3D models of cultural relics with more accurate geometric shape and textures. It has been tested that the average single point of 3D model can be controlled within 0.02mm. But in the process of practical application, the acquisition of the same cultural relic by both laser scanning and photogrammetry technology will double the time and manpower, which makes the collection funds double correspondingly. In addition, for the safety of cultural relics, the time to collect a cultural relic is quite limited. The more complex the artifacts are, the longer the collection time will be. In most cases, there is no enough time for the acquisition with the two methods, so it is difficult to realize the large-scale data collection by using both the methods.

It can be seen form the evaluation of data quality with different collection methods that the method used in this stage fails to balance the cost, efficiency and results at the same time. Laser scanning method can obtain spatial model data of high precision, but the accuracy of texture data is not enough; the mapping accuracy with photogrammetry is high, but the model precision is not enough; the combination of the two methods can reach the data accuracy, but the efficiency is not high.

3.3 A new acquisition scheme

According to the above comprehensive evaluation mode of "cost-efficiency-result", high-quality 3D data of cultural relics shall be obtained without being restricted by funds and time, so appropriate processes shall be established to improve both the efficiency and accuracy of data and thus obtain stable high-quality 3D data, which is the basis for long-term preservation of 3D data of all cultural relics.

A new precision control method is added to photogrammetry - QR code and image control device for close range photogrammetry of cultural relics [16]. By balancing the cost, efficiency and results at the same time, this method can not only ensure data accuracy, but also satisfy the needs of low cost and high efficiency.

However, why do we choose to increase precision control on the basis of photogrammetry rather than improve the other two methods? In the long-term preservation of cultural relics, there is a high requirement on both 3D spatial data and texture data, which is mainly because accurate collection and preservation of cultural relic patterns is also very important, but manual mapping is used in laser scanning, which makes it difficult to improve the mapping accuracy. In terms of the combination of laser scanning and photogrammetry, data must be collected twice, which makes it difficult to improve the efficiency. Based on the accumulated collection experience of 3D data of cultural relics, the cost, efficiency and achievements shall be weighed at the same time. Therefore, photogrammetry is used as the main acquisition method in general collection process for both more accurate 3D spatial data and texture data.

If there is no absolute orientation in the reconstruction calculation of cultural relics with photogrammetry, the 3D model obtained only has relative spatial relationship, but fails to restore the actual size of cultural relics. The simple method of absolute orientation is scale restriction; that is, in the process of data collection, a standard piece suitable for photogrammetry 3D reconstruction is placed beside to take photogrammetry photos together with cultural relics, and then the size of the cultural relics is processed by software in the proportional constraint way by giving the size of standard piece for 3D reconstruction. However, the accuracy of 3D data reconstructed by this method is not high, which is difficult to meet the preservation needs of 3D data.

The method of image control is the basic method for absolute orientation of photogrammetry 3D reconstruction. However, when the cultural relics are digitized in 3D, they cannot be arranged on the object measured as usual photogrammetry due to the limitation of protected cultural relics. Therefore, the feature points of cultural relics are usually used as the image control points. Generally, cultural relics rarely have obvious feature points satisfying the spatial distribution requirements of image control points, which will lead to the difficult selection of feature points on photos and unreasonable distribution of image control points in photogrammetry data processing, thus greatly affecting the accuracy of 3D reconstruction. Many cultural relics even have no image control points distributed reasonably. Moreover, the control points of artificial image are selected and judged by humans in a large number of photos under heavy workload, and it is influenced by personal factors. Therefore, the operation efficiency is low; the results are inconsistent; and it is difficult to guarantee the accuracy.

In order to solve this problem, a QR code and image control device for close range photogrammetry is used to ensure the data accuracy and efficiency of 3D reconstruction of photogrammetry. The device includes a number of QR code pieces (image control points) and support frames to connect and support the QR codes: the former includes a QR code calibration plate connected with the support frame and a QR code set on the calibration plate; the latter is composed of several closed rings in horizontal direction and several connecting rods in vertical direction. These QR code calibration plates are arranged in plum-blossom shape under the action of the support frame (distributed according to the rule of image control points with photogrammetry). In the process of data collection, the support frame is set around the cultural relics, and the QR code is set far away from the cultural relics. It can be assumed that the two are the same structure. Then, the camera is used to shoot the cultural relics and QR code at the same time, and the processing software is used to process the shooting results. The QR code image control device is a special standard part with fixed and accurate dimensions. The 3D spatial coordinates of each QR code are arranged in plum-blossom shape and surrounded around the cultural relics. In photogrammetry software, the 3D coordinate information on the control frame is automatically recognized and matched as the coordinate of image control points, which is used for the absolute orientation of 3D reconstruction and thus obtain accurate geometric information of cultural relics.

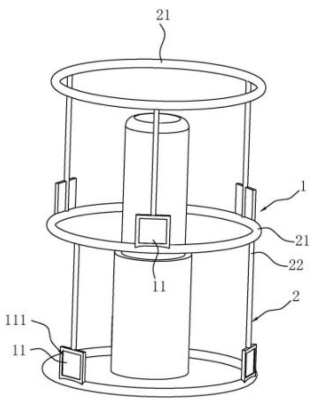

Figure 1 Schematic diagram of QR code and image control device for close range photogrammetry of cultural relics.

1. QR code piece; 11. QR code calibration plate; 111. QR code slot; 2. Support frame; 21. Closed ring; 22. Connecting rod.

According to the different sizes and heights of cultural relics, QR code and image control devices with different layers are used to match the cultural relic size, and the distance from support frame and QR code to cultural relics shall be the best to improve the 3D data accuracy of cultural relics as far as possible.

By using the device, the 3D reconstruction of photogrammetry can automatically calculate data in absolute orientation, which eliminates the process of manual point selection and prick point, and the greatly improves working efficiency. What is more, image control points are distributed in a scientific and reasonable manner, which is not related to the characteristics of cultural relics. Therefore, the accuracy of 3D reconstruction is improved and guaranteed well.

The comprehensive evaluation model of "cost-efficiency-result" is used to evaluate the data acquired in different experiments, and it has been proved that the photogrammetry method, which is controlled by QR code and image control device, has the characteristics of low cost, high efficiency and high data precision, so it can effectively solve the imbalance between the cost, efficiency and result in the current stage.

3.4 Grading scheme

The 3D data obtained by this method can basically meet the needs of preservation of 3D data of cultural relics, but it is not enough to ensure its long-term utilization. The ultra-high-precision 3D data cannot be directly applied to the actual projects due to the large number of the high-precision 3D model surfaces, the large amount of high-resolution multi-color map data, and the limitation caused by the computer hardware and mobile phone hardware.

It has been concluded from various applications that preservation level, online application level and offline application level shall be designed to satisfy different requirements and different application scenarios.

Table 2 Model classification requirements

Level classification	Grid model	Texture mapping
Preservation level	Dimension error≤0.2mm Integrity≥96%	≥600dpi Position error of mapping with grid model ≤0.30mm
Online application level	The number of triangles = 50% of the corresponding level of archives, or ≤10 million Integrity=100%	The number of textures≤5 Texture resolution ≤2 times of that of the corresponding level of archives Position error of mapping with grid model ≤0.60mm
Offline application level	The number of triangles≤0.3 million Integrity=100%	The number of textures≤3 Single texture: 8192 × 8192 pixels Normal map for the parts with surface undulation≤ 2mm

Preservation level is used for the preservation of 3D data of cultural relics, with the error of point size of grid model≤0.2mm, model integrity≥96% and texture resolution≥600dpi. It is suggested to use manual modeling and mapping to repair the model and texture maps if the collection of cultural relics is too complex, or there are backlight, hollow and occlusion, or it is impossible to fully obtain all data of the complete cultural relic model during the collection process.

Offline application level is used for offline display of high-precision 3D data of cultural relics. On the basis of archive level model, the optimization is carried out by using the method of thinning or topology, and UV spreading is carried out. The offline application level model is made to retain normal map. According to the characteristics of cultural relics and the display requirements, the number of offline application level models shall be controlled within the range from 30% to 60% of the preservation level, or ≤ 10 million in principle. In addition, the holes of the preservation level model are repaired according to the trend, and the integrity of the grid model is restored to 100%. There shall be no more than five UV maps.

Online application level is used for online display of 3D data of cultural relics. The presentation level model is made by using the method of thinning or topology, and the normal map is preserved. According to the characteristics of cultural relics and the display demands, the number of possible display level models shall be controlled within 0.15-0.6 million on the basis of ensuring the display effect of cultural relics. The number of UV maps shall not exceed three, and the pixels of single texture resolution shall be 8192 × 8192.

3.5 Storage scheme

According to the different requirements of the above-mentioned data reuse process, the data shall be stored in a hierarchical way in the storage stage. In order to keep the cultural relics for a long time, the 3D data of cultural relics shall be recorded and stored in all directions. At the same time, a unified storage scheme shall be proposed for data sharing among museums.

Therefore, the following storage scheme is currently used by the Palace Museum for the storage of 3D data of cultural relics. The structure of the storage file system for a single cultural relic is shown as below:

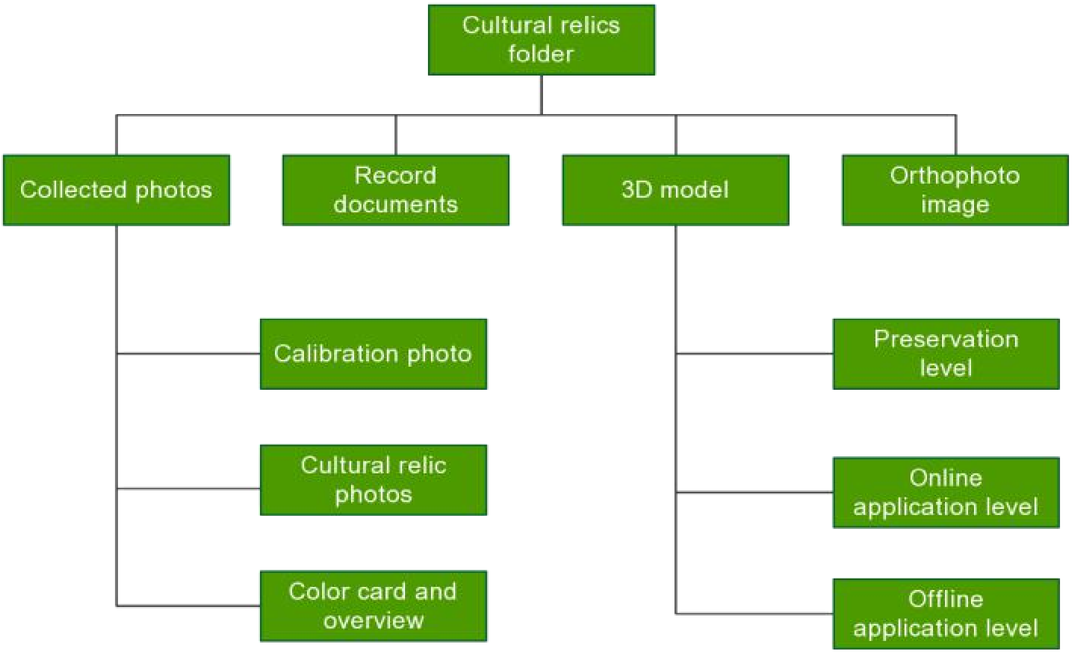

Figure 2 Structure of storage file system for 3D data of cultural relics.

4. Method Research

4.1 Case analysis

In the process of data collection, cultural relics shall be put in the soft light shed, with reasonable light sources set outside the shed and the interference of the extra light shielded. Then, the cultural relics are safely placed in the center of a smooth circular turntable in the soft light shed, and the QR code and image control device is reasonably set outside the cultural relics, both of which are regarded as a whole. And the both are then photographed simultaneously with a camera. One photo will be taken for each 15 degrees of rotation until 360 degrees in a circle. After that, the camera position will be adjusted to take photos in different strips. After the photos of all the strips are taken for one position of cultural relics, the QR code image control device shall be removed for the later shooting of other positions until the photos cover all the surfaces of the cultural relics. The cultural relic in Fig. 3 is Qianlong teal candlestick with enamel crabapple pattern, with the height of 39.5cm, and a two-layer image control device is used. The cultural relic in Fig. 4 is Guangxu vase of the colorful cloud thread, with the height of 27cm, and a four-layer image control device is used. All the photos of cultural relics are imported into the photogrammetry software for processing, and then the 3D reconstruction texture model with high precision can be obtained.

Figure 3 Two-layer image control device.

Figure 4 Four-layer image control device.

The models after 3D reconstruction are shown in figure 5 and figure 6.

Figure 5 3D reconstruction model of Qianlong teal candlestick with enamel crabapple pattern.

Figure 6 3D reconstruction model of Guangxu vase of the colorful cloud thread.

It has been shown by various experiments that this method has the characteristics of low cost and high efficiency, and the obtained 3D model has high precision, small error and accurate mapping. In addition, the geometric accuracy is almost close to the error of laser scanning. The average single point error of the 3D model can be controlled at 0.02mm, which meets the data quality requirements of long-term preservation of the 3D data of cultural relics.

Taking the 3D reconstruction model of Qianlong teal candlestick with enamel crabapple pattern as an example, the data classification is shown as follows:

Table 3 Preservation classification of 3D reconstruction model of Qianlong teal candlestick with enamel crabapple pattern

Level classification	Number of grid models	Number of texture maps
Preservation level	1534649	5 maps, 8192x8192 resolution of each map
Offline application level	911776	5 maps, 4096x4096 resolution of each map
Online application level	287130	1 texture map, 1 normal map, 8192x8192 resolution of each map

Taking the 3D reconstruction model of Qianlong teal candlestick with enamel crabapple pattern as an example, the data storage structure is shown as follows:

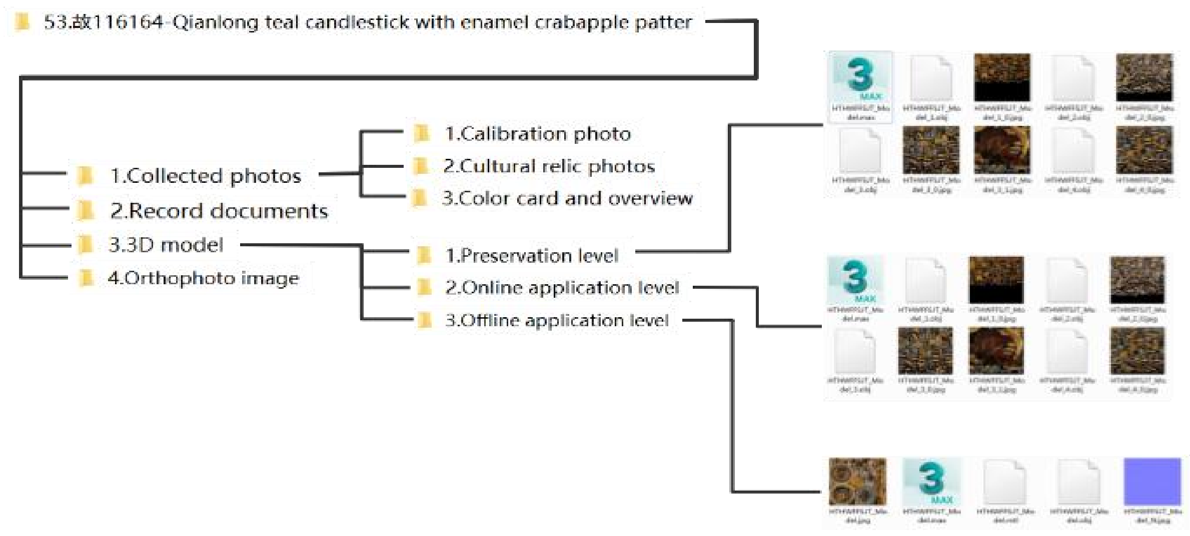

Figure 7 the data storage structure of the 3D reconstruction model of Qianlong teal candlestick with enamel crabapple pattern.

4.2 Application practice

For many years, the Palace Museum has been implementing the 3D digitization of cultural relics, and has applied 3D data precision control to practice, which provides reference for data preservation, data utilization and the formulation of national 3D digitization standards.

In terms of using high-precision 3D data of cultural relics for long-term preservation, the Palace Museum has completed five 3D digitization projects of cultural relics in total: "2019 data acquisition and processing project of 3D online display of cultural relics in the Palace Museum", “3D data acquisition and processing of cultural relics in 2020 in the Palace Museum", "3D reconstruction of religious cultural relics in 2020 in Yangxin Hall", “Data acquisition and processing project of 3D online display of cultural relics in the V Palace Museum”, and "Research and demonstration of key standards for digital protection of movable cultural relics (taking ancient paintings and bronzes as examples)". 3D data acquisition and processing of nearly 400 pieces of high-precision cultural relics have been completed by 2020.

In addition to using high-precision 3D data for the digital protection of cultural relics, the Palace Museum also uses a variety of precision 3D data in different practical fields. In the exhibition hall of the Ceramic Museum of the Palace Museum, the application level 3D data is also used for offline display, where the audience can interact with the virtual cultural relics by using the touch screen in 360 degrees, and the cultural relics can be seen in details. The display level data is used for online display on the official website of the Palace Museum, where visitors can "put cultural relics in their hands" and interact with them in zero distance without leaving home. After the 3D data of these cultural relics is reused, they are successfully transformed into digital products, providing services for experts and audiences. The Palace Museum is continuously using high-precision 3D data of cultural relics for related application research and development practice, which has laid a foundation for the determination of the technical indicators of the follow-up standards.

Based on the experience and practice of 3D digitization of cultural relics, the Palace Museum has taken the lead in completing the project supported by National Science and Technology - “Research and demonstration of key standards for digital protection of movable cultural relics (taking ancient paintings and bronzes as examples)”, and is taking the lead in compiling the Beijing local standard - Technical Specifications for 3D Digitization of Cultural Relics - Implements. The establishment of the two standards aims to improve and promote the unified high-quality 3D data of cultural relics, so that the 3D data can be preserved and reused in the whole field of cultural relics.

5. Conclusion

In order to build a long-term preservation system of 3D data of cultural relics, a case study of precision control of 3D data of cultural relics based on photogrammetry is carried out in combination with the comprehensive evaluation mode of "cost-efficiency-result", which solves the insufficient data quality, insufficient funds and low efficiency in the preservation of cultural relics, and balances the contradiction among cost, efficiency and results to a certain extent, thus providing new ideas and methods for the long-term preservation of 3D digital heritage by cultural relic institutions. In the face of tens of thousands of cultural relics, there is still a long way to go for the long-term preservation of 3D digitization, and it is urgent to expand the digitization of cultural relics. It is of great significance to strengthen the construction of digital talent teams, develop more equipment with high precision, high speed and high cost-performance, and promote the unified digital process standard for the long-term preservation of 3D digital cultural relics.

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