A method for cultural relic virtual restoration using 3D fine model

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Abstract: According to the requirement of the cultural relic protection project, this paper mainly researches cultural relic virtual restoration using 3D fine model. We present a novel method for finding relics restoration evidence base on regression model and restore them using 3D models. The method is efficacious verified by an example of DaZu Thousand-Hand Bodhisattva rock carving. We successful estimate the defect length of Bodhisattva hands via regression equation.

Key words: Thousand-Hand Bodhisattva, restoration evidence, virtual restoration, regression model

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1 Introduction

In thousands years of the history, rich and precious cultural relics have been inherited. However, as elapse of the time and influence of human activity, cultural relics are continuously destroyed. How to use an advanced technology to protect them has became an urgent problem. Compare to cultural relics in the collection of cultural institution, rock carving relics usually preserve an adverse environment and vulnerable to suffer weathering and other disease. That can lead to the relic surface out of shape, damaged part lost and difficult to find reliable basis for restoration.

With 3D laser scanning technology development and application, this kind of non-contact measurement technology makes 3D digitizing easily for cultural relics which has complex geometrical structure (Kanaya, et al. 2000). The technology of cultural relic 3D reconstruction (Hu ShaoXing et al. 2006; Zhang Rui et al. 2007; Qiu ZhaoWen & Zhang TianWen, 2008) achieves the geometric coordinate of the real world objects can be accurately acquired and used in archaeological studies. The more accuracy model and the lower difficulty of modeling technology provide important data base for culture relics virtual restoration. Virtual restoration, a digital technology simulates repair relics in computer, provides an effective and supplementary means for relic restoration project (Wu Yuhua, et al. 2011). This technology is used in historical relic conservation area in many applications, such as to reduce operational difficulty in handwork, to avoid relics further damage due to improper treatment and to use in digital exhibition.

Recently years, extensive works (Zhang Xianying, 2003; Ru Shaofeng, 2004; Huang Qixing et al. 2006) have been done in the area of automatic re-assembly for fragmented relics. But these kind of methods are applied only to the case of fragments succeed in finding and the damage boundary reveal clearly. These methods are hard to restore the incomplete relics. At present, The way of virtual restoration incomplete relics is interaction of human and computer. A related work (Henning, et al. 2002) studies a set of algorithms based on multiresolution subdivision surfaces that perform at

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interactive rates and enable intuitive cut-and-paste operations. And other scholars (Yu Yizhou, et al. 2004) introduce a novel approach to mesh editing with the Poisson equation as the theoretical foundation, their approach can produce desirable and pleasing results for both global and local editing operations, such as deformation, object merging, and smoothing. However, these methods repair the model only by the manipulator's own thought. Owing to the influence of cognition can bring about one relic restorer for one remediation effectiveness. There is no standard of tentative basis. Excessive human factors will not be able to make the relics restored to the closest historical shape. It is the significant regret both cultural relics and archaeology. Therefore, how to restore the cultural relics using reliable restoration basis become such a daunting challenge.

This paper presents a new method to search for the incomplete relic restoration evidence and restore them using 3D fine models. The length, a kind of geometrical characteristic , of the missing part in the relics is computed base on linear regression model.

2 The process of virual restoration

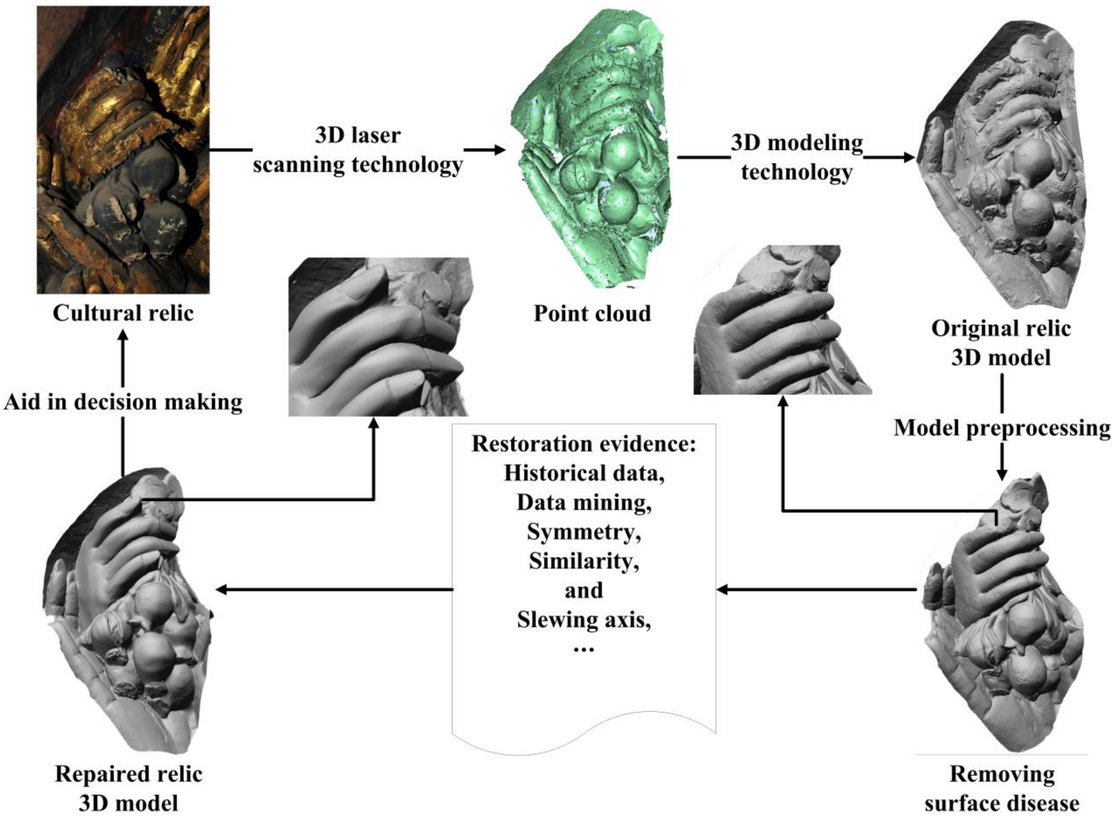


Fig1. The process of virtual restoration

The process of cultual relic virtual restroation is shown in Figure 1. 3D laser scanner obtains the coordinate information of relic surface and saves the format of point cloud. As a high precision replica of cultural relic is reconstructed in computer, the original relic model is acquired before the point cloud is rendered into 3D model via 3D reconstruction technology. In the step of model preprocessing, the surface disease , such as gold foil warped and rock mass fracture, is removed which affects simulation restoration. The damage or the missing parts of relic reconstructed by data merge and data stitch base on the restoration evidence such as shape of similarity and symmetry, historical data, data mining and some other methods. At last, the termination products apply to aid decision in cultural relic protection project. They include three dimensional calculation, construction points and section plan.

In the whole process, the core issue is how to accurately find out the shape on missing part. Objectivity is the key in the process. A geometric method (Li Chunlong, et al. 2006) is proposed to estimate the axis of fragmented relic and restore its profile curve, revolving the profile around its axis generates the original model. A recent study (Min Lu, et al. 2011) present a method for simultaneously restoring the original shapes of group of similar objects using a matrix recovery technique to achieve the restoration. However, these methods still cannot satisfy the requirements of variety shapes and large number of scattering relics.

3 The experiment area

(a) visible light photograph (b) rendered image using 3D data

Fig.2 images of The Thousand-Hand Bodhisattva rock carving

The Thousand-Hand Bodhisattva rock carving is located in the country of Dazu in Chongqing municipality (Figure 2). It is an important part of the Dazu stone carvings. The most famous and distinctive symbol of this stone carving is nearly a thousand Kan-yin hands radial present and hold different musical instruments used in Buddhist around the Bodhisattva. From a distance, the rock carving has been covered by gold foil and preserved approximately integrated, general preservation magnificent momentum, facial morphology and resplendent landscape. However, after careful observation , the rock mass is weathering and the gold foil falls off due to the age-old. A large number of Bodhisattva hands have impaired in different levels, seriously affected the artistic value of the cultural relics. Different attitude of the Bodhisattva hands embody different Buddhist meaning, these issues never fail to fascinate archaeologists, archaeological received a comparatively large restriction because those incomplete fingers. Clearly, if those hands can be accurately repaired to historical shapes, as many archaeologists believe, that will be help to know the rock carving better. There is no doubt that restoring the original shape of the Thousand-Hand Bodhisattva rock carving is primary problem, either for the protection of cultural relics or the archaeological research. The greatest difficulty encountered is unable to determine the original length of the incomplete fingers.

The data of point cloud has been acquired via 3D laser scanner by our research group then rendered the 3D models. According to measuring and statistic on the model, The Thousand-Hand Bodhisattva rock carving statue is 7.7m high, 12.5m width with total of 829 Kan-yin hands and an arm. The rock carving is virtual divided 99 (9*11) small rectangle areas, and every hand named an ID in order to convenient recognition.

4 The regression model

4.1 Work process

In order to find the repair evidence, mutilation of different fingers length in the same hand for virtual restoration, we statistics two s of data. One is the length of ring fingers and middle fingers in 88 intact Bodhisattva hands as experimental data. And another group includes 20 hands as verification data. The pipeline of work process is shown in Figure 3.

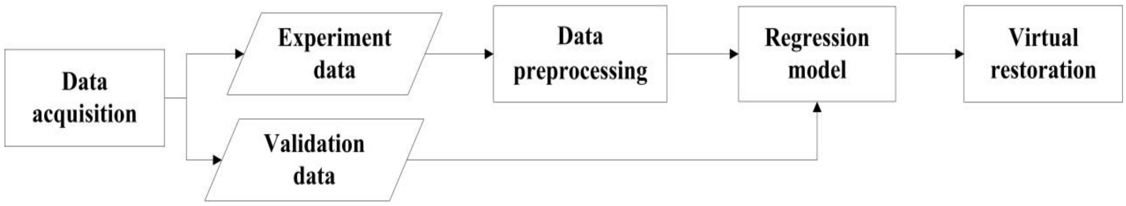


Fig.3 The pipeline of finding restoration evidence

Using the experimental data fit the first regression model. The purpose is data preprocessing which can find out the abnormal data. Then we establish the ultimate regression model after ruled out a small part of the abnormal data. Furthermore, the second regression equation reflects the proportional relation between the length of ring finger and middle finger, and gives the prediction interval used in small adjustment of construction. Finally, the regression equation is validated by the validation data.

4.2 Method

Regression analysis is a mathematical tool to modeling the correlation between a dependent variable y and one or more explanatory variables denoted x. The case of one explanatory variable is called simple regression model. In our research, we use simple linear regression, the regression model is descript in equation 1:

$$Y = \hat{a} + \hat{b}x. \tag{1}$$

Where:

$$\hat{b} = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}.$$

$$\hat{a} = \frac{1}{n}\sum_{i=1}^{n} y_i - \frac{\hat{b}}{n}\sum_{i=1}^{n} x_i.$$

4.3 data preprocessing

The purpose of data preprocessing is to find the abnormal point from the original data. Although we can find some by eyeballing, such as the point in the red box is an obviously one in Figure 4, but we cannot find all the information via subjective judgment. Therefore, the use of statistical methods for abnormal point recognition makes the whole process more scientific and objective. From the statistic speaking, the regression model can describe the proportional relation between the fingers. But this method base on the least squares principle is very sensitive with extreme values. Abnormal points can lead to the regression model make a comparatively large error, one not enough accurately predict value cannot provide essential help for finding the length of incomplete fingers. From the historical relic speaking, the abnormal points are also a focus from archaeologist. In this stone carving, these abnormal points are regarded as causing by original rock mass, holding Buddhism article, special carving skill, coordinate system of a relic or other unknown reasons. The spatial analysis of abnormal points on the relic may unfold the new archaeological information. Therefore, extracting abnormal points is not only in order to improve the precision of the regression model but also to have a significant archaeological discovery.

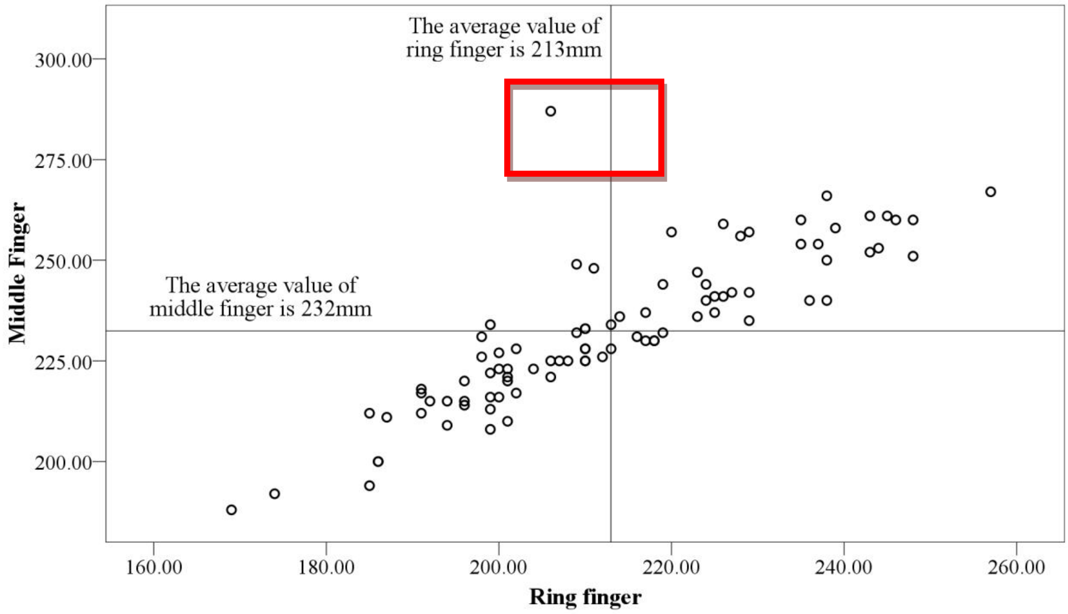


Fig.4 The Scatter diagram of experiment data

In this paper, the length of ring finger defined as the explanatory variable *x*, the middle finger defined as the dependent variable *y*. And three standards of parameters are introduced in judging the abnormal points.

4.3.1 Centered leverage value

The first paremeter is called centered leverage value, h_{ii}. This value aimed at identifying data of observation that are far away from corresponding average predictor values. But leverage points do not necessarily have a large effect on the outcome of fitting regression models. This parameter is used to detect the length of ring finger whether are abnormal, the standard is h_{ii}<0.025.

$$h_{ii} = \frac{(X_{i1} - \bar{X}_1)^2}{SSX} \tag{2}$$

Where,

$$SSX = \sum_{j=1}^{n} (X_{i1} - \bar{X}_1)^2$$

4.3.2 Student deleted residual

Studentized residual is the quotient resulting from the division of a residual by an estimate of its standard deviation. The meaning of Student deleted residual is calculate the studentized residual excluding the data *i* . It reflects the impact of i in the predict value. It can determine y whether abnormal, $SRE_{(i)} < \pm 1$.

$$SRE_{(i)} = SRE_i \left(\frac{n-p-1}{n-p-2} - \frac{SRE_i^2}{n-p-2}\right)^{-\frac{1}{2}} \quad (3)$$

Where,

$$SER_i = \frac{e_i}{MSE\sqrt{1-h_{ii}}}$$

in the above equations:

e_i is the crude residual

MSE is the mean square error of the regression model

n is total amount

p is the number of fitted parameters in the model.

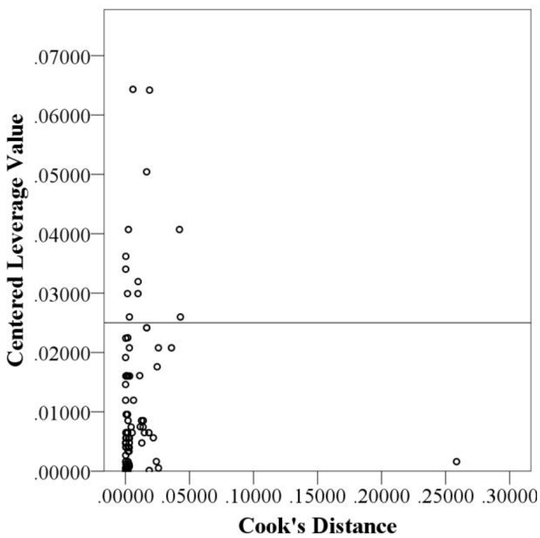
4.3.3 Cook' Distance

Cook's distance is a commonly used estimate of the influence of a data point when performing least squares regression analysis. Cook's distance measures the effect of deleting a given observation. Data points with large residuals or high leverage may distort the outcome and accuracy of a regression. in our analysis , the Cook's distance D_i<0.01 is considered to abnormal points.

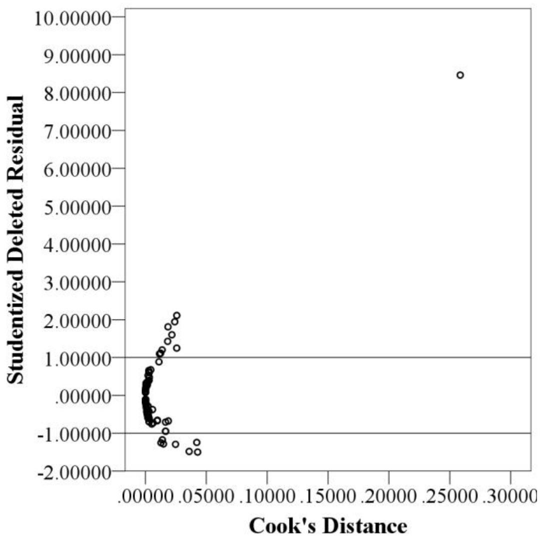
$$D_i = \frac{e_i^2}{p\,MSE}\left[\frac{h_{ii}}{(1-h_{ii})^2}\right] \quad (4)$$

5 Experimental results and discussion

5.1 Abnormal point analysis



(a) Centered leverage value



(b) Studentized deleted residual

Fig.5 The results of three parameters

The figure 5 shows the calculate results of the centered leverage value, the student deleted residual and the Cook's D. From the relationship between them as we can see in figure 5, a part of Cook's D is normal when the centered leverage value and the student deleted residual are large. It means that although the value of the middle finger and the ring finger are partial small, but it ratio between the fingers still accord with the linear regression model. These types of hands, bigger or smaller than the normal, are recorded for future research by archaeologists. Those data need not to be removed as abnormal points, because they do not make a big impact of the regression model. But the meaning of another case of large Cook's D is totally different than former. These points will be regarded as abnormal point to exclude. These small parts of hands do not confirm the proportion between the fingers. The reason is we not hope for a small group of abnormal data resulting in the regression model prediction accuracy greatly reduced. The prediction interval excess spread will make the whole thing become meaningless.

5.2 Regression analysis

Via the data preprocessing, 22 hands are precluded in the second regression analysis. Figure7(a) shows the fitting lines in the twice and the points of the remaining 66 hands, the dotted line is the result of first regression analysis and the real line is the second which is fitted after data preprocessing. The final regression equation is:

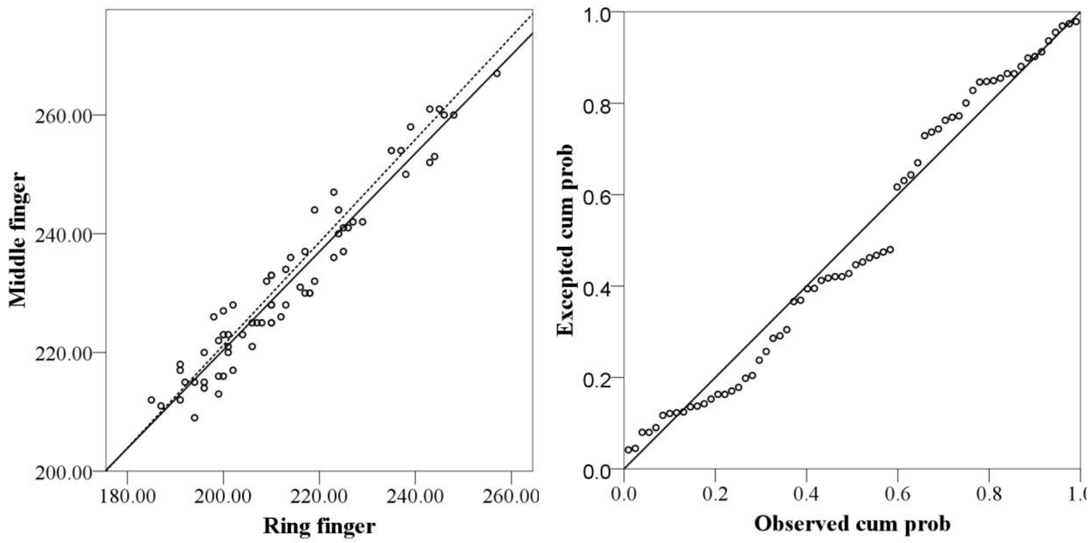
$$Y=0.828x+54.819 \quad (5)$$

Where：

Y is the length of middle finger, X is the length of ring finger, unit is mm.

In this linear regression model, the coefficient of determination R^2 provides a measure of how well the regression line approximates the real data points. From the equation 5 we can know a coefficient of determination ranges from 0 to 1 and an R^2 of 1.0 indicates that the regression line perfectly fits the data.

$$r^2 = \frac{SSR}{SST} = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}. \quad (6)$$



(a) (b)

Fig.6 The results of linear regression model

In this group of data, R^2 is 0.993. It proves the reliability of the equation is well in statistics. The residual of the linear regression model is normal distribution as shown in the figure 6(b). For a simple estimating, the prediction interval is determined by two times the standard error: $2\hat{\sigma} = 7.2\text{mm}$.

5.3 Data validation

Table 1 The length Measure value and prediction value of middle fingers

Hand ID	Measure value /mm	Prediction value /mm	Error /mm	Hand ID	Measure value /mm	Prediction value /mm	Error /mm
2-3-S1	234	230	4	4-9-S15	229	226	3
2-3-S2	222	225	-3	4-9-S12	227	230	-3
2-9-S3	227	230	-3	5-1-S6	234	229	5
2-9-S1	217	227	**-10**	5-7-S3	221	221	0
3-11-S2	228	224	4	5-7-S2	240	242	-2
3-10-S5	237	234	3	5-9-S9	234	234	0
3-5-S5	233	234	-1	6-5-S3	238	237	1
3-1-S5	225	227	-2	6-11-S6	227	230	-3
4-1-S5	222	225	-3	6-10-S11	209	217	**-8**
4-9-S16	224	225	-1	6-10-S10	225	228	-3

In order to ensure the suitability of regression model, we are verified the equation 5 with 20 hands as a validation data. In the 20 validation data, 18 hands are interior the prediction interval. The rest of two hands, the residual is beyond the prediction interval 1mm and 3mm. That can be clearly seen in figure 8.

We believe that the linear regression equation can predicate the length of hands in the Thousand-Hand Bodhisattva rock carving. The prediction interval is a room for adjustment which is used in the virtual restoration.

5.4 Virtual restoration

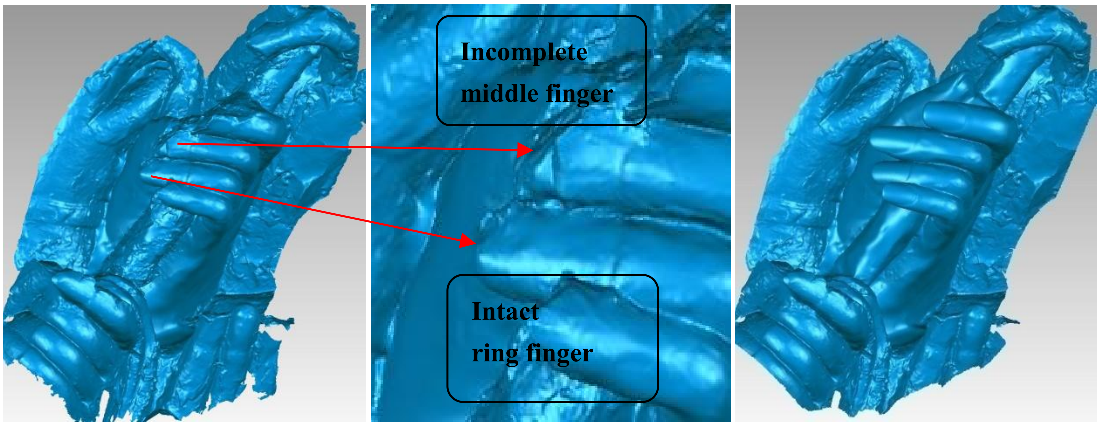
In the hand ID 8-9-S7, the length of ring finger is 218mm base on measuring on the model. And the length of middle finger is 216mm but it is incomplete because of weathering. In order to calculate the length of the missing part, the prediction value is 235±7mm via the equation 5. Therefore, the damage area should be grown approximately 19mm. The ±7mm used in adjustment by artistic skill. The virtual restoration effect of 8-9-S7 is shown in figure 7.

6 Summary

We have proposed a norvel method for relic virtual restoration using 3D fine model. In the all of steps, we heavy focus on the restoration evidence which is the key of scientificalness and objectivity.

Regression model is the most convenient mathematical tool in studying dependence relation. Therefore, this method will be great appliance, specifically a group of cultural relics, if some kind geometrical characteristic of relics is correlation.

Experimental results on the length of incomplete fingers from Thousand-Hand Bodhisattva rock carving verify the effectiveness of our method. The incomplete hand sculpture have objective evaluate the accuracy of our restoration effect. We believe the method will provide significant benefit to cultural relic protection project and archaeological studies.



a) The original model. b) Fractionated gain of the fingers. c) Virtual restoration effect.

Fig.7 ID 8-9-S7 Virtual restoration effect

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