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Identification of ancient ceramics by digital shape characterization

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Shapes are important clues for the identification of ancient ceramics. In this study, digital extraction methods of shape characterization were discussed, using samples of flared mouthed porcelain bowls produced in Jingdezhen Hutian Kiln from the Five Dynasties to the Song and Yuan period. By employing the techniques of image enhancement, edge detection and curve fitting of Matlab, the method using digital shape characterization has advanced accuracy and effectiveness of traditional identification which is based on visual and tactual inspections. Together with the increasingly applied compositional data analysis and thermoluminescence dating technique, the method will further improve and upgrade the scientific identification system for ancient ceramics.

ancient ceramics, shape, Matlab

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1 Introduction

China has a long history of ceramics making. Its wide-ranged products which exhibit diversified styles and excellent craftsmanship have rich cultural implications and are of high collection and research values. With the improvement of material life in China, collection activities of all kinds have been unprecedentedly flourishing. Massive public funds have poured into museums for acquirement of their collections, and a large part spent on those of ancient ceramics. This has given a significant boost to their soaring auction prices, and an offer of tens of or even hundreds of millions of RMB for a piece is not a rarity. Under the temptation of large economic profit, cases of ancient ceramic forgery and fraudulent authentication have been on the rise, which has caused huge financial losses to many institutions and individuals. Therefore, how to develop a scientific identification system for ancient ceramics has been a major concern of the researchers in this sector. Traditionally, an ancient ceramic piece would put to the look and feel tests. The examination with the eyes and hands of its shape, decorative pattern, glaze, body and official mark could give clues to its dating and provenance. However, the limitation to the sensory perception the traditional method is based on has made it imperative to develop a scientific, systematic and quantitive approach to ancient ceramic identification for higher accuracy and reliability. So far, two modern techniques for the research in technological sciences have been used in ancient ceramic identification: thermoluminescence dating technique [1] which tests the accumulated radiation dose from the environment of the time elapsed, and compositional data analysis [2, 3] which measures the chemical composition and raw material formula. Their feasibility has been proved and they have begun to be widely applied to ancient ceramic research and identification. As is well-

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known, ancient ceramics are not only technical products, but also vehicles of culture and art. Although the two modern identification methods mentioned above have their advantages over the traditional counterpart, they have their own weaknesses and limitations [4]. The traditional method focuses on the characteristic art expression of ancient ceramics, including their shape, decorative pattern, and so on, which provides very important evidence for their dating and provenance. If the sensory experience of the traditional method can be accurately quantified and systematically organized by employing the approaches of modern information processing and mathematical analysis, the digital extraction of the characteristic data can be realized. By incorporating in the two modern techniques, the method using digital characterization will contribute significantly to the practice of ancient ceramic identification in China.

Nevertheless, the research in this aspect is far from enough. Take for example the study on shapes of ancient ceramics, an important piece of evidence for their identification. In recent years, a few scholars have done some relevant research [5], but they either directly measured the sizes of an article, including its total height, its foot and mouth diameters [6], and so forth, or "sliced" the article at equal intervals and then digitized its shape features with the obtained diameters of each "slice" [7]. Their work has indicated the usefulness of quantitive shape characterization for ancient ceramic identification, but their methods are too complicated, and more unsatisfactorily, they can only acquire part of the shape data, failing to grasp the whole. But the recent progress of computational mathematics and computer technology has made it possible to obtain the complete data of the whole and establish the identity of ancient ceramics by digital shape characterization. Therefore, Matlab as a powerful mathematical tool in image enhancement, edge detection, curve fitting, and other image processing tasks has been adopted to establish an approach to digitizing the shape characterization of ancient ceramics using as samples the flared mouthed porcelain bowls unearthed from Jingdezhen Hutian Kiln from the Five Dynasties to the Song and Yuan period in this study. The contour curves of the samples have been obtained through digital image acquisition, Matlab-based preprocessing and edge detection for the quantitive analysis of their time-relevant shape features as new scientific evidence for their dating and provenance.

2 Samples

Jingdezhen, one of the Four Famous Towns in China, has won its world renown as a major producer of porcelain. Production of commercial porcelain wares in Hutian, Jingdezhen, began in the period of the Five Dynasties and continued through Song, Yuan and Ming Dynasties. The sites of the ancient ceramic kilns in this area have been the best places for the research on the development of Jingdezhen ceramic technology and art from the 10th-14th centuries [8]. Plates and bowls were the main products from Hutian Kilns. The flared mouthed bowl was one of their classic forms. In this study, unearthed Hutian flared mouthed bowls have been used as test samples. Samples Htw01–Htw05 were produced in the period of the Five Dynasties, Htw06–Htw11 in Song Dynasty and Htw12–Htw17 in Yuan Dynasty [9]. Typical samples are shown in Figure 1.

3 Shape feature extraction for digital characterization of ancient ceramics

The shape of an ancient ceramic piece can be defined in two ways: one by its dimensions that can be directly measured, including the total height, the diameters of the mouth and the foot, etc; the other by its contour curve. A hand-thrown round ware is mathematically a solid of revolution. Its shape is constructed by rotating the contour curve around a straight axis. Therefore, a contour curve that virtually exhibits all the shape features of ancient ceramic wares can provide substantial evidence for dating and provenience study. To explore its application benefit for ancient ceramic research and identification, digital shape characterization was performed on flared mouthed Hutian bowls. Their contour curves were obtained through image acquisition, transformation, enhancement, edge detection and curve fitting, from which their time-related characteristics could be extracted.

The first step to extract the digital shape characteristics of an ancient ceramic ware is to acquire the image. Choices of the shooting angle, lighting, background, etc. for ancient ceramic photography will affect the accuracy and reliability of the resulted digital information. In this study, eye-level shots of the bowls were taken to prevent image distortion. The camera was positioned 1 m off the sample to be shot. The background color was versatile medium grey which could set off its image without having its contour dissolved

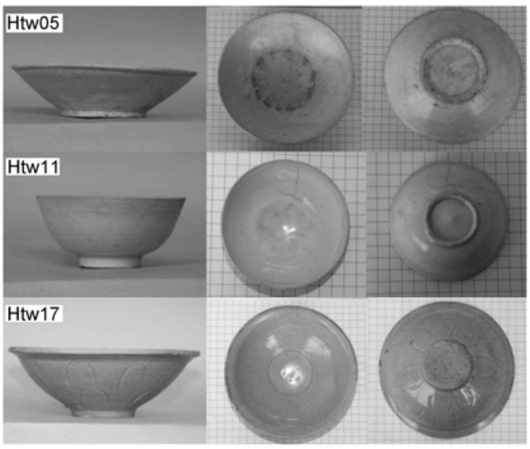

Figure 1 Photographs of typical samples.

into the background. The contrast between the sharp and the blurred was used to emphasize the image of the subject. The focus was on the sample to be shot in the foreground and the depth of field was properly controlled to deemphasize the background. As a result, the image of the subject became more distinct and emphasized for better detection of its contour in digital image processing. High-angle shots were taken of the mouth and the foot of each sample (Figure 1) for the acquisition of their characteristic data. Although there are still some questions in the process of image acquisition, they will not be discussed here in this paper because of limited space.

Then the acquired images of those ancient ceramic forms were processed in Matlab. As one of the three major pieceses of the mathematical software, Matlab has very strong image processing capability, and its language is user-friendly for non-computer experts, so it's suitable for digital shape feature extraction of ancient ceramics. According to the visual characteristics of ancient ceramic images and the contour detection requirements, the obtained digital images were processed in Matlab through image transformation, enhancement, recognition, etc. The performance followed the process shown in Figure 2.

The technique of image transformation is capable of enlarging the image scale of an ancient ceramic ware and correcting the distortions of the image caused by the motion of a camera during exposure through image translation, rotation and so on to ensure the data to be extracted from the digital image are accurate and reliable. Image enhancement is to reduce or remove the differences (the so-called deteriorations or degradations) [10] between the digital image of an ancient ceramic ware and its original per se, which may have been produced due to camera resolutions, photography backgrounds and other causes during image generation, transmission and transformation. By using the techniques of grayscale transformation, histogram equalization, filtering in the frequency domain, the visual effect of the image can be improved, so that the contour of the image will be sharper for easy recognition in edge detection, thus facilitating the feature extraction of the ancient ceramic shape.

In the research on ancient ceramics, the contour curve of a ceramic ware [11] can provide all the information about its shape, because it fully represents the characteristics of its construction; as far as the visual characteristics of an image is concerned, its contour is more easily accessible to human visual perception, and is capable of making more impact on the vision system [12]. Moreover, the biggest variation on grayscale occurs on the edge of an image, which makes edge detection possible. It uses a first-order or second-order derivative expression of the grayscale magnitude to identify the edge pixels. With the extracted edge pixels, the contour curve of a ceramic shape can be created by Matlab polynomial curve fitting. It's found in the process that the goodness of fit [13] varies slightly with the order of the polynomial equation. The coefficient of determination used for evaluating the goodness of contour curve fitting of flared mouthed Hutian porcelain bowls approximated 1 when the fitting order is 4, which indicated that the obtained contour curve matched the original shape profile best. Additionally, the coefficients of the polynomials of all orders higher than 4 approximate zero. Therefore, the fourth-order polynomial was found to be the optimum for contour curve fitting of Hutian bowls. The extraction process of digital shape features for selected ceramic samples is shown in Figure 3, and the curve fitting results for their contours are listed in Table 1.

4 Discussions

Previous quantitive study on the shape of ancient ceramic wares was primarily based on the direct measurement of its dimensions, including the diameters of its mouth and foot, its total height, etc. In this study, the mouth diameters and heights of flared mouthed Hutian porcelain bowls from different dynasties ave been measured (Table 2), and their scatter plot has been made (Figure 4). As is indicated in Figure 4, the mouth diameters of flared mouthed Hutian porcelain bowls vary between 12–20 cm, their heights between 5–8 cm, and the differences in those dimensions between the bowls from different dynasties are not remarkable, so it's difficult to find any time-dependent feature in the scatter plot. Therefore, the quan-

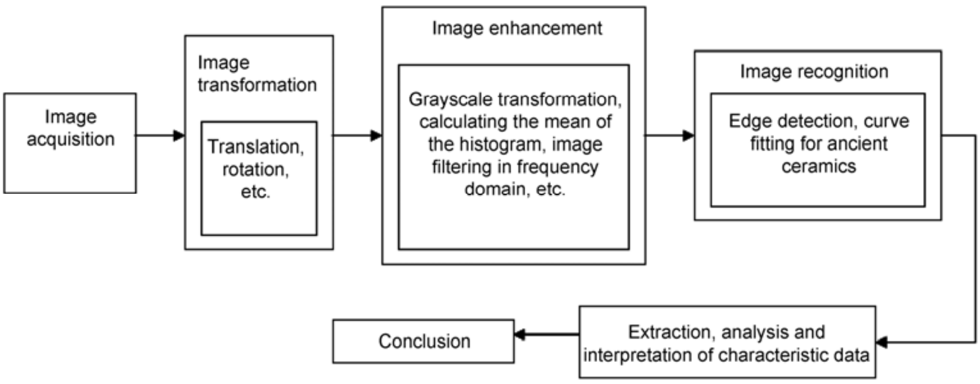

Figure 2 Digital image processing.

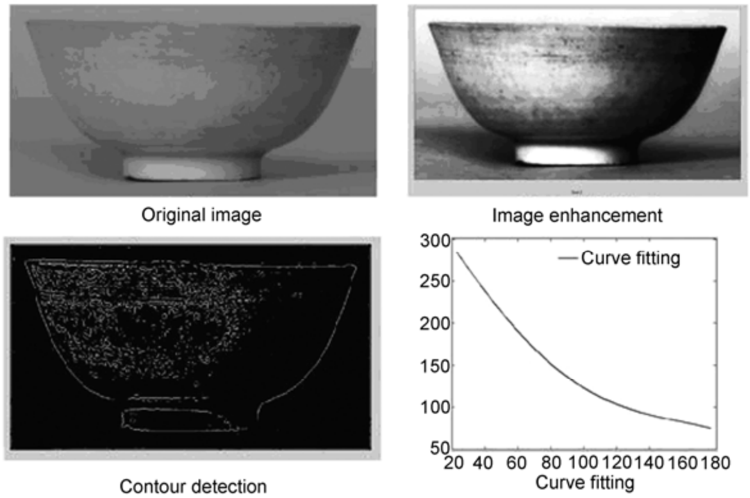

Figure 3 Construction characteristics extraction for test samples.

Table 1 Curve fitting coefficients for different orders of polynomials

	X_4	X_3	X_2	X_1	X_0
Htw01	-2.24×10^{-6}	0.001	–0.041	–0.282	140.032
Htw02	-6.27×10^{-6}	0.001	–0.043	–0.801	102.028
Htw03	-2.99×10^{-6}	0.001	–0.057	0.206	140.296
Htw04	-3.92×10^{-6}	0.001	–0.070	0.453	146.806
Htw05	-8.29×10^{-8}	3.430×10^{-5}	–0.004	–0.660	196.033
Htw06	-1.32×10^{-6}	0.000	0.011	–3.571	229.085
Htw07	-7.10×10^{-6}	0.002	–0.221	6.932	127.585
Htw08	1.06×10^{-7}	0.000	0.036	–4.064	231.048
Htw09	-5.34×10^{-6}	0.002	–0.152	4.396	100.131
Htw10	2.87×10^{-7}	0.000	0.014	–1.732	150.996
Htw11	-2.63×10^{-7}	7.32×10^{-5}	0.005	–3.293	353.875
Htw12	-2.57×10^{-6}	0.001	–0.061	–0.042	166.252
Htw13	-4.95×10^{-6}	0.001	–0.112	1.949	116.733
Htw14	-1.69×10^{-5}	0.004	–0.256	4.586	116.024
Htw15	-1.36×10^{-5}	0.004	–0.310	8.959	35.536
Htw16	-9.30×10^{-6}	0.003	–0.243	7.330	54.761
Htw17	2.47×10^{-9}	5.41×10^{-6}	–0.002	–1.006	336.841

titive approach to ancient ceramics through the simple measurement of its dimensions has its deficiencies.

In Matlab, however, contours of ancient ceramic wares can be extracted from their digital images, their curve functions can be obtained, which contain a large multitude of latent information about their shapes. In addition, the functions on those curves are capable of doing various kinds of mathematical operations and make further research possible. Flaring out on the rim or mouth is an important characteristic of those samples of Hutian porcelain bowls. So, in this study, the slopes at the mouth of flared Hutian bowls from different dynasties have been calculated from their contour fitting curves to characterize their flares. Curvature, the ratio of change angle in the direction of a tangent that moves over a given arc to the length of the arc, can indicate the state of being bent at a point on the curve. An inflection point is a point on the curve at which the second derivative of the curvature is equal to zero while the third derivative is not. It signals the change of the concavity and convexity. So, curvature and inflection points can also be used to characterize the shape of flared mouthed bowls. Table 2 presents the slopes at the mouth, the numbers of inflection points and the maximal curvatures of the flared mouthed Hutian bowls from different dynasties calculated from the functions on the contour fitting curves.

As is revealed in Table 2, there are 2 inflection points on the contour curves of the samples from the Five Dynasties and the Yuan Dynasty, while there is only 1 on those of the Song Dynasty samples. This means that the contour curve curvatures or concavities of the samples from the Five Dynasties and Yuan Dynasty have changed twice while those of the Song Dynasty samples have changed only once and that the shapes of the Song Dynasty flared mouthed bowls are relatively simple. It proves that the number of

Table 2 Dimensions of flared mouthed bowls and their characteristic data computed from their contour fitting curves

Sample code	Mouth diameter (cm)	Height (cm)	Slope at the mouth	Maximal curvature (cm^{-1})	Number of inflection points
Htw01	18.6	6.8	−1.435	0.013	2
Htw02	12.6	4.5	−1.730	0.016	2
Htw03	17.0	6.5	−1.589	0.012	2
Htw04	17.0	7.0	−1.998	0.010	2
Htw05	20.3	5.6	−1.982	0.012	2
Htw06	16.0	8.5	−0.921	0.012	1
Htw07	11.9	6.8	−0.718	0.033	1
Htw08	10.6	5.2	−0.677	0.008	1
Htw09	14.8	6.8	−0.692	0.029	1
Htw10	20.0	7.0	−0.586	0.009	1
Htw11	10.3	4.7	−0.985	0.011	1
Htw12	19.4	7.0	−0.805	0.036	2
Htw13	17.3	6.2	−1.096	0.039	2
Htw14	17.4	6.8	−1.063	0.059	2
Htw15	19.8	8.2	−1.171	0.154	2
Htw16	15.0	6.4	−0.989	0.190	2
Htw17	18.1	8.3	−0.909	0.056	2

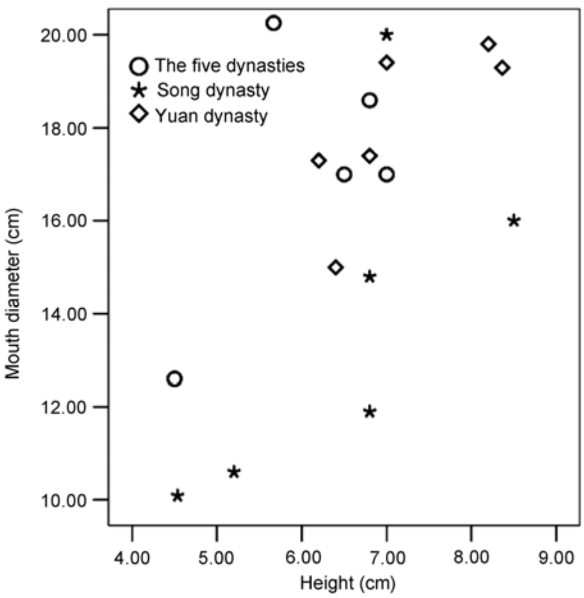

Figure 4 Scatter plot for mouth diameters and heights of flared mouthed Hutian porcelain bowls from different dynasties.

inflection points on the contour curve of a flared mouthed Hutian porcelain bowl can be used as an important characteristic for its dating.

Figures 5 and 6 are boxplots for the maximal curvatures and slopes at the mouth of flared Hutian bowls from different dynasties. Figure 5 shows that the slopes at the mouth of flared bowls from different dynasties vary remarkably, while the values of the samples from the Five Dynasties is around −1.75, from Song Dynasty considerably up to about –0.75, and from Yuan Dynasty down to about −1. The slope at the mouth of a flared bowl indicates its outward inclination. The tendency of their slope values from upward to downward with the time may be concerned with the change in the aesthetics and lifestyle of the people in different dynasties. As is displayed in Figures 2 and 6, the maximal curvatures of the contour curves for flared mouthed Hutian bowls from the Five Dynasties and Song Dynasty vary between 0.01–0.03 cm^{-1}, which means their curvature radii are very large and reach above 33 cm; for those from Yuan Dynasty, however, the maximal curvatures of their contour curves see a steep rise, even up to 0.19, with their curvature radius of only 5.3 cm, and their curves are very sharp. Both their maximal curvatures and slopes at the mouth are clearly time-dependent. They provide an important evidence for tracing the shape evolution from the Song Dynasty delicately-constructed to the Yuan Dynasty strongly-built [14] and can afford a clue to the dating of the flared mouthed Hutian bowls.

5 Conclusion

Mathematical tools like Matlab have been used to extract digital shape features from flared mouthed Hutian porcelain bowls produced in Jingdezhen from the Five Dynasties to the Song and Yuan period. Results show: 1) the shape of an ancient ceramic piece is characterized not only by its dimensions like its mouth and foot diameters, its height, etc. but also by its contour curve obtained through image enhancement, edge detection, curve fitting and other digital image processing techniques, an indicator of the aesthetic taste, ceramic technology and craftsmanship of its time as well as an important parameter for its dating and provenience study and scientific identification; 2) as an important

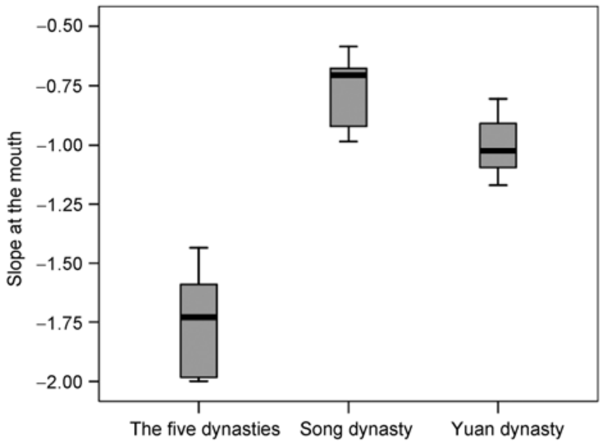

Figure 5 Boxplot of slopes at the mouths of flared Hutian bowls from different dynasties.

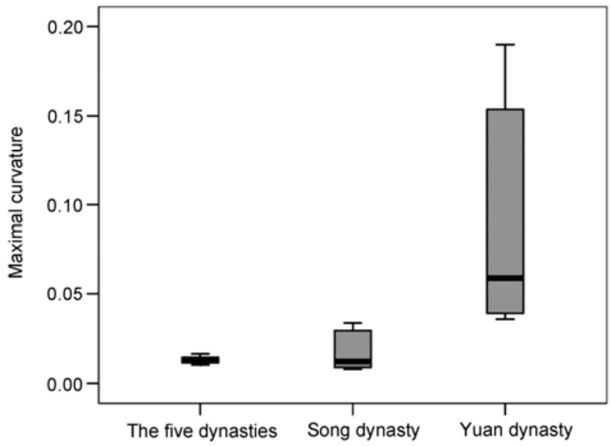

Figure 6 Boxplot of maximal curvatures for flared mouthed Hutian bowls from different dynasties.

tool for digital characterization extracting of ancient ceramic wares, Matlab is very effective in quantitively analyzing and systematically organizing the empirical experience from sensory perception the traditional identification method is based on, so that the experience of the traditionalists can be accumulated and transmitted while the identification accuracy and reliability of an integrated method can be enhanced; 3) the slopes at the mouth, the maximal curvatures and the numbers of inflection points computed from the fitting contour curves for the flared mouthed Hutian porcelain bowls from different dynasties can be used as crucial parameters for their dating study, which has solved the problems in which the direct size measurement of ceramic wares including their foot and mouth diameters, their heights has failed.

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1 Wang W D, Xia J D, Zhou Z X, et al. Thermoluminescence dating of ancient Chinese porcelain using a regression method of saturating exponential in pre-dose technique. Sci China Ser E-Tech Sci, 2006, 36(5): 525–540
2 Wu J. Science and Technology Research and Identification of Ancient Ceramics (in Chinese). Beijing: Science Press, 2009. 138
3 Wu J, Li J Z, Deng Z Q, et al. Dating of official blue and white porcelain wares from Jingdezhen in different periods. Sci China Ser E-Tech Sci, 2004, 34(5): 516–524
4 Chen T M, He N. Computer-aided classification of pottery food containers from the Second Period of Erlitou Culture to the current of People's Parks in Henan//Essays on Archaeological Cultures (in Chinese). Beijing: Cultural Relics Publishing House, 1989. 340–345
5 Yang Y S. Ceramic Modeling Art (in Chinese). Beijing: Higher Education Press, 2004
6 Liu X Y, Zhu J, Yan Y. An application of statistics to research into pottery in Sang Dynasty (in Chinese). Relics from South, 2007, 3: 67–72
7 Luo H J, Yang Y, Wang F, et al. Study on the configuration characteristics of the Yaozhou porcelain bowl in different periods (in Chinese). China Cer Ind, 2003, 10(6): 1–4
8 Liu X Y, Bai K. Investigation report of Hutian Kiln in Jingdezhen (in Chinese). Cultural Relics, 1980, 11: 39–49
9 Jiangxi Institute of Cultural Relics and Archaeology, Jingdezhen Folk Kiln Museum. Ancient Kiln Sites Discovered in Hutian, Jingdezhen (in Chinese). Beijing: Cultural Relics Publishing House, 2007
10 Gonzalez R C, Woods R E. In: Ruan Q Q, Ruan Y Z, et al., trans. Digital Image Processing (in Chinese). Beijing: Publishing House of Electronics Industry, 2005
11 Ma H Z. Archaeological Artifacts Drawing (in Chinese). Beijing: Peking University Press, 2008. 1–25
12 Huo H T. Digital Image Processing (in Chinese). Beijing: Beijing Institute of Technology Press, 2002. 79–98
13 Dong J X. Research and application of Chi square goodness of fit test in the equal probabilistic test of random sequence. In: 2010 Second ETP/IITA World Congress in Applied Computing, Computer Science, and Computer Engineering (ACC 2010), 2010. 490–493
14 Liu X Y. Shape characteristics and their causes of classic bowls from Hutian Kiln in different periods (in Chinese). Cultural Relics, 1980, 11: 50–60