

Three-dimensional Model Display of Museum Based on Mobile Augmented Reality Technology



Na Yue*

Department of Tourism, Taiyuan University, Taiyuan, Shanxi 030032, China
nyuemail@126.com

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Abstract. With the development of science and technology, exhibition forms of museums also have had new ways. In this paper, based on mobile augmented reality (AR) technology, the three-dimensional model display of museum is studied. Firstly, the AR technology was introduced briefly. Then, the mobile AR system of museum was designed, the model was built by using 3DS Max, the system was positioned by WiFi, and the three-dimensional model was realized by using Speeded-Up Robust Features (SURF) algorithm to extract natural features and track and register them. In the system test, firstly, WiFi positioning accuracy and tracking registration accuracy was tested, and the results showed that the average positioning error was 0.55 m, which showed that it had a good adaptability to ambient occlusion and could meet the requirements of the system. Then, some cultural relics in the museum were displayed in three-dimensional model, which proved the effectiveness of this method. This study provides some theoretical bases for the application of mobile AR technology in museums and is conducive to the further promotion of mobile AR technology.

Keywords: augmented reality, mobile platform, museum, three-dimensional model

1 Introduction

Traditional museum exhibition is usually in the form of glass cabinet and instructions. Cultural relics are placed in glass cabinet, and simple text introduction on the illustration plate can only play a limited role in helping people understand cultural relics. Moreover people's visiting time is not enough for them to thoroughly understand cultural relics, and museums can not give full play to the function of disseminating culture. The emergence of augmented reality (AR) technology has created new opportunities for museum display forms [1]. Through AR technology, people can interact with cultural relics in real time in the process of visiting. Combining virtual with real scenes, people can be provided with voice prompts, video commentary, three-dimensional model and other information to realize the change of visiting mode from static to dynamic. The development of mobile devices also provides powerful equipment support for the realization of AR technology. AR technology has been applied in many fields. Huang et al. [2] studied the outdoor AR system, developed an outdoor AR system based on 3D Geographic Information System (GIS), which has the ability of outdoor registration and proved the feasibility of the system through experiments. It can be applied in underground facilities mapping, urban planning and other fields. Wang et al. [3] studied the application of AR technology in dental surgery. Through real-time automatic stereo 3-D imaging, the patient's three-dimensional image was covered on the surgical site to provide guidance for doctors. The experiment found that the overlap error of this method was only 0.71 mm. Lv et al. [4] designed an AR game with eleven dynamic gestures based on AR technology; users could interact with the game by hand and foot gestures in front of the camera. Kelly et al. [5] applied AR technology to education; through AR real-time display of anatomical structures such as skeleton and muscle, students and teachers could better carry out clinical reasoning and create an attractive learning experience. Currently, AR technology is mainly applied in fields such as

* Corresponding Author

medicine, industrial maintenance and military, and research about the application of AR technology in museum exhibition is seldom [6]. Gimeno et al. [7] pointed out the application of AR technology is greatly limited as museum cannot use artificial label and the computation ability of smart phone is limited. Tom Dieck et al. [8] found through the application of AR technology in a small British museum that AR technology had economic, social, cognitive, cultural and historical heritage educational values and can improve visitor satisfaction to generate positive public praise. Jim Nez Fernandez-Palacios et al. [9] designed an ARCube system which could render 1:1 scale between digital and real object, and it could realize interactive visualization of archaeological discoveries and could be applied in museum exhibitions. Pedersen et al. [10] developed a TombSeer software which could make users being immersed in the museum space through a holographic head-up interface, with powerful gestures and visual augmented reality experience. This study focused on the mobile platform based AR technology. A museum mobile AR system based on mobile AR technology was designed, and the key technologies were studied to realize museum three-dimensional model display, which can make some contributions to the promotion and application of mobile AR technology in museum exhibition.

2 AR Technology

AR technology generates multi-sensory virtual environment by computing crossbow, superimposes the real world and the virtual world to enhance the real world and help users to enhance their understanding of the real world. The principle of AR technology is to recognize the markers in the real world through the camera, and register the virtual information (such as three-dimensional model) established by the computer with the real world, and display it, so as to realize human-computer interaction. With the development of AR technology, it has been widely used in fields such as medical [11], entertainment, education and military. AR technology mainly includes three key points:

(1) Tracing registration. It refers to the registration of virtual images in the real world [12], i.e., locating and recognizing the real objects, transforming them into virtual information and storing them in the computer. At present, the most commonly used method is to locate and track the targets based on image recognition.

(2) Display technology. It refers to transforming virtual information in computer to form images after superimposing it with the real world. At present, computers and tablet computer are usually used as display devices, among which mobile devices become the ideal platform for AR display because of their convenience and operability.

(3) Human-computer interaction. It refers to the realization of human-computer interaction through touch screen technology. Users can interact with the real world and virtual world through the control of the screen [13].

3 Design of Mobile AR System for Museum

3.1 System Framework

In order to display the three-dimensional model of museum, a mobile AR system was designed, and its structure is shown in Fig. 1.

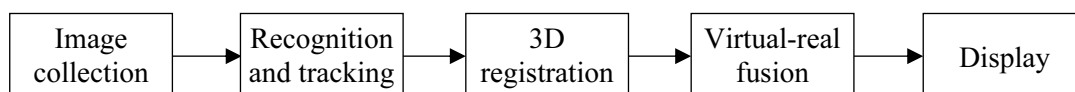


Fig. 1. Mobile AR system

The real-world scene images were collected by mobile camera and then transmitted to the recognition and tracking module for processing and processing. The location information of the target in the real world was determined by three-dimensional registration. Then the virtual three-dimensional model was superimposed on the real-world picture through the virtual-real fusion module and displayed by the display to achieve AR.

3.2 Key Technologies

Three-dimensional modeling. In order to superimpose the computer data and real world, support of three-dimensional modeling technology is needed. At present, the main three-dimensional modeling technologies are SolidWorks, UG, AutoCAD, 3DS Max and so on. 3DS Max [14] was selected for three-dimensional modeling, which can carry out polygon modeling and achieve bending, rotation and other effects. The OBJ file of the three-dimensional model was obtained by using 3DS Max. The file format can be opened, edited and saved by the writing board.

Positioning by WiFi. WiFi is used to locate mobile devices. In indoor positioning, WiFi is a good positioning technology with low cost and high speed. Fingerprint positioning method [15] was used to calculate user location. Firstly, the fingerprint identification database of indoor environment is established, the environment grid is divided, and the wireless access point (AP) is deployed. Then the Receive Signal Strength Indicator (RSSI) knowledge of each AP is calculated and stored in the database. The contacts between indoor staffs may lead to unstable WiFi. Therefore it is necessary to preprocess RSSI value to improve positioning accuracy. The preprocessing way is as follows.

In general situation, RSSI value fluctuates around the stable value and shows random component x_0 . Gaussian model $p_0 = p + x_0$ is introduced, where $p_0 \sim N[u, \sigma^2]$. Density function can be expressed as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-u)^2}{2\sigma^2}}, \text{ where } u \text{ stands for mean value, } u = \frac{1}{n} \sum_{i=1}^n x_i = \frac{x_1 + x_2 + \dots + x_n}{n} \text{ and } \sigma^2 \text{ stands for variance, } \sigma^2 = \frac{\sum_{i=1}^n (x_i - u)^2}{n-1}.$$

The records in RSSI domain database of AP were matched to estimate the specific location:

RSSI of AP of a point that needs detection is supposed as $rss_i = [rss_{i_1}, rss_{i_2}, \dots, rss_{i_n}]$. The record in the database is $RSSI_i = [RSSI_{i_1}, RSSI_{i_2}, \dots, RSSI_{i_{N_i}}]$, where n represents the number of AP, N_r represents the number of records in the database, $i \in [1, N_r]$, and N_i represents the number of AP in the i -th record. The matching algorithm can be expressed as:

$$L = \arg \min_{i \in [1, N_r]} \|rss_i - RSSI_i\|. \quad (1)$$

Natural feature extraction. As the original appearance of cultural relics displayed in museums can not be destroyed, the method of artificial marking feature can not be used [16]. Therefore, the method of natural feature recognition was used in this study, which recognizes based on the characteristics of the target image. Speeded-Up Robust Features (SURF) algorithm [17]. The Hessian matrix of a point in an image whose scale is σ is defined as:

$$H(\varepsilon, \sigma) = \begin{bmatrix} L_{xx}(\varepsilon, \sigma) & L_{xy}(\varepsilon, \sigma) \\ L_{yx}(\varepsilon, \sigma) & L_{yy}(\varepsilon, \sigma) \end{bmatrix}, \quad (2)$$

where four items such as $L_{xx}(\varepsilon, \sigma)$ stands for the convolution of the second derivative of the Gauss function at point ε and the image. The determinant of the Hessian matrix is: $\det(H) = L_{xx} \times L_{yy} - L_{xy}^2$.

In SURF algorithm, the second derivative of Gauss is approximately replaced by a square filter, which is represented as D_{xx} , D_{yy} and D_{xy} . Then there is $\det(H_{approx}) = D_{xx} \times D_{yy} - (0.9 \times D_{xy})^2$. A multi-scale image pyramid can be built to find feature points on different scales, and stable SURF feature points can be obtained.

Tracking registration. The camera coordinate system is supposed as $X_c Y_c Z_c$, and the world coordinate system is supposed as $X_w Y_w Z_w$. The mapping relationship between them is:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} V_{3 \times 3} & W_{3 \times 1} \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} = T_{cm} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}. \quad (3)$$

The relationship between camera coordinate system and world coordinate system is represented by matrix T_{cm} in a size of 4×4 , i.e., the external posture of camera; $V_{3 \times 3}$ is three rotational components of camera with regard to the world coordinate system; $W_{3 \times 1}$ represents three translation components.

According to the pinhole imaging principle, the mapping of point $P(X_c, Y_c, Z_c)$ in the camera coordinate system on 2D imaging plane is supposed as $P'(X_u, Y_u)$ (Fig. 2), the focal distance of camera is represented by f . Then there is $x_u = \frac{X_c}{Z_c} f, y_u = \frac{Y_c}{Z_c} f$, which can be expressed as following using homogeneous coordinates:

$$\begin{bmatrix} hu \\ hv \\ h \\ 1 \end{bmatrix} = P \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix}, P = \begin{bmatrix} s_x f & 0 & x_0 & 0 \\ 0 & s_y f & y_0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (4)$$

where P represents the internal parameter matrix of camera, s_x, s_y represent scaling factors, and (x_0, y_0) represents pixel center.

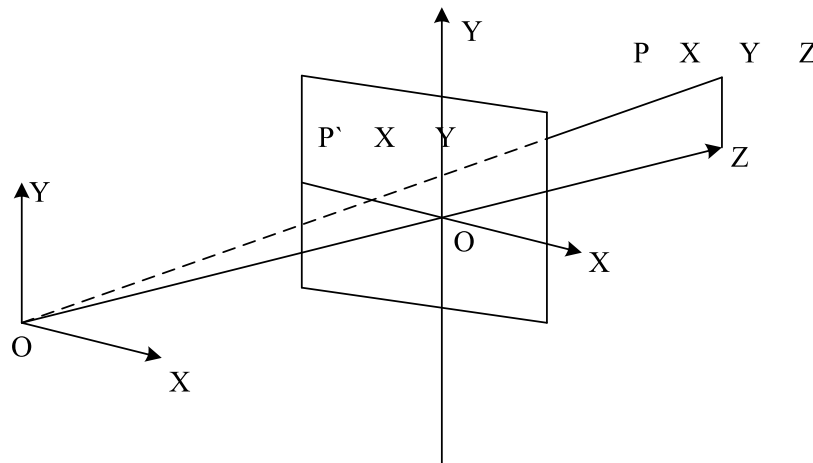


Fig. 2. The pinhole imaging principle

The virtual coordinate system is supposed as $X_v Y_v Z_v$. The transformation between the virtual coordinate system and world coordinate system can be expressed as:

$$\begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = A \begin{bmatrix} X_v \\ Y_v \\ Z_v \\ 1 \end{bmatrix}, \quad (5)$$

where A represents a known change matrix.

To sum up, the transformation between the virtual coordinate system and imaging plane can be expressed as:

$$\begin{bmatrix} u \\ v \\ h \end{bmatrix} = P \cdot T_{cm} \cdot A \cdot \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix}. \quad (6)$$

The registration of virtual objects can be realized by calculation.

4 System Testing

4.1 Test Environment

The mobile device screen used in this study had 4.5 inches and 854×480 pixels, the CPU used was Qualcomm MSM8625Q with 1.25 GHz. ROM was 4GB, RAM was 1GB, and the camera had 5 million pixels. The AP used was TP-LINK TL-WA850N.

4.2 Establishment of System Platform

To realize the successful application of algorithm in mobile terminal, Android NDK working area needs to be established, and the detailed procedures are as follows.

- (1) The source code is put into <project>/jni;
- (2) <project>/jni/Android.mk is established;
- (3) Create<Project>/jni/Android.mk is selected;
- (4) Native code is compiled. Command CD runs to enter engineering path, and then command ndk-build:
`$cd<project>`
`$<ndk>/ndk-build`

runs.

- (5) Tools run to copy shared library.
- (6) SDK is compiled into apk and released.

4.3 Positioning Accuracy Test

In the museum shown in Fig. 3, six AP were arranged, and 10 test points were set for testing. RSSI was matched by fingerprint positioning method. Researchers carried mobile devices and moved in the museum. After receiving RSSI data from mobile phones, the server calculated the position of researchers in real time. The test results are shown in Table 1.

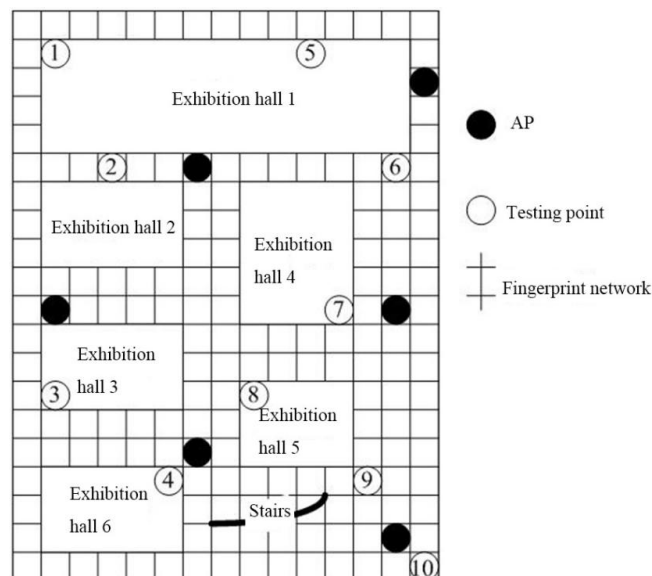


Fig. 3. Positioning accuracy test

Table 1. Test results

Test point	1	2	3	4	5	6	7	8	9	10	Average error/m
Error value /m	0.2	0.4	0.3	0.5	0.4	0.6	0.2	0.9	1.3	0.7	0.55

It was found from Table 1 that the maximum error between the positioning result and actual measurement result was 1.3 m, the minimum error was 0.2 m, and the average error was 0.55 m. The positioning errors of five test points were smaller than 0.5 m. In the perspective of the positioning results, the accuracy of the positioning algorithm could meet the requirements of mobile AR museum system.

4.4 Tracking and Registration Accuracy Test

Feature information damage and incomplete feature extraction were simulated by means of partial occlusion, and the accuracy of tracking registration was observed at that time. The accuracy refers to the degree of deviation between the model of tracking registration and actual position. The larger the deviation degree, the lower the accuracy. The results are shown in Fig. 4.

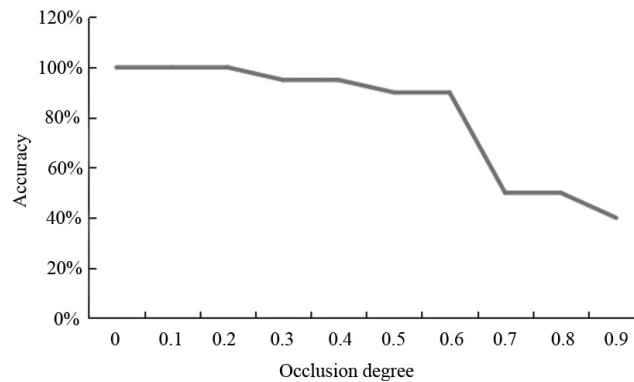


Fig. 4. The results of the tracking registration accuracy test

It was found from Fig. 4 that the tracking registration accuracy of the system had obvious changes with the increase of the occlusion degree. Under the situation of occlusion, the feature points extracted by SURF algorithm were incomplete, which made the system unable to obtain accurate tracking registration data and led to the distortion between the model and actual position. When the occlusion degree was within 0.7, the distortion was small, which would not affect system modeling. When the occlusion degree exceeded 0.7, the system accuracy greatly reduced, which showed that the system had good adaptability to the ambient occlusion. But in the establishment and display of three-dimensional model, it is necessary to avoid target to be occluded as far as possible to avoid influence on system accuracy.

4.4 Three-dimensional Model Display

The actual scene map of a museum and the actual texture map of the target object were acquired by the camera, and then the three-dimensional model of the actual scene was constructed by 3DS Max and imported into unity3D. After the processing of sound effect, rendering and plug-in, the three-dimensional models were made. Some three-dimensional museum models are shown in Fig. 5.

The SURF algorithm was used to extract and match the natural features of the target. After matching, the tracking registration was carried out. The three models were integrated into the real world through the transformation between the camera coordinate system, world coordinate system and virtual coordinate system. Through the development of Unity, users can view the cultural relics in 360 degrees on the screen of the mobile phone, obtain the relevant information of the cultural relics through touch control technology, and understand cultural relics in an all-round way by means of voice interpretation, text annotation and video broadcasting. Taking the body of Lady Xinzhui as an example, its three-dimensional model display in the mobile AR system is shown in Fig. 6.

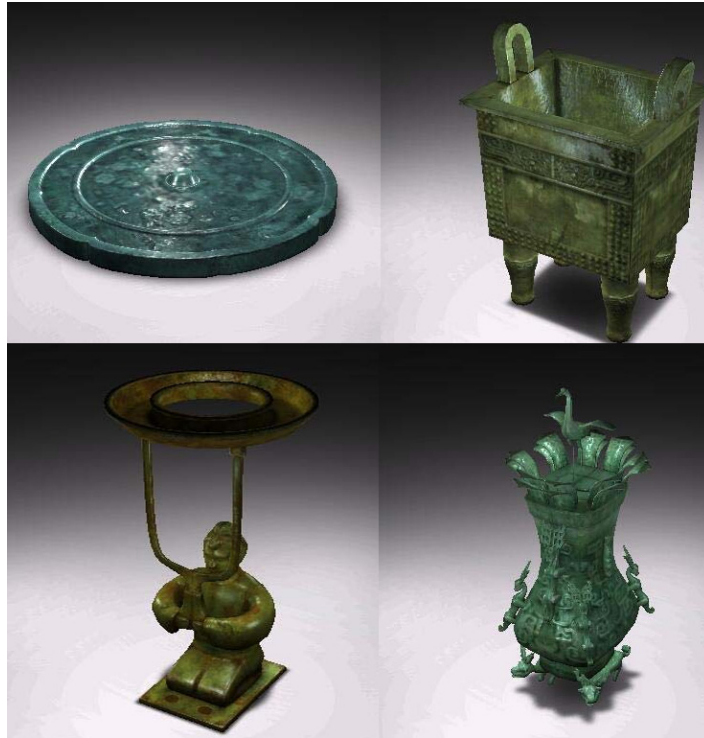


Fig. 5. Positioning accuracy test



Fig. 6. Model display

5 Discussion

As an important carrier of cultural dissemination and inheritance [18], museums are important places for people to acquire history, art, science and other cultures, which can not only promote national culture, but also enhance people's aesthetic concepts, and play a very important role in people's lives. The emergence of AR technology has brought new opportunities to the development of museums. Museum based on AR technology can bring people multi-sensory experience, enhance people's interest in visiting, and promote people to actively enter the museum, so as to better carry out the dissemination and inheritance of culture. But at present, the application of AR technology in museums relies mostly on computers, which is not convenient enough. Mobile AR technology based on mobile devices can bring people a stronger interactive experience. Mobile AR refers to the AR system built on mobile devices. Users can move freely, more convenient and efficient when they use it. In the process of visiting museums, visitors can always move. Therefore, mobile AR has more important application values in museum exhibition.

In this study, a mobile AR system for museum was designed, which realized three-dimensional modeling through 3DS Max and positioning through WiFi. The fingerprint positioning algorithm was used. In order not to destroy culture, natural features instead of manual labeling features are not used in

feature extraction. The feature points of targets were extracted using SURF algorithm. The tracking registration algorithm was briefly described. The virtual three-dimensional model was superimposed with the real world through the transformation of the coordinate system and displayed. In the system test, the positioning accuracy of the system was tested at first, and an average error of 0.55 m was obtained. Then some cultural relics models were displayed. The display of cultural relics models were realized on the mobile screen. Visitors can view the cultural relics through the screen touch technology in an all-round way and learn more about the relevant information of cultural relics.

The application of mobile AR technology in museums is a new field, which can realize the restoration and reconstruction of cultural relics, enable visitors to see the restoration effect of cultural relics through the screen and bring immersive experience to visitors, enrich the display information of culture, and help people understand cultural relics comprehensively through text, video, audio, etc. [19]. Positioning technology can be realized tour guide function, providing route guidance for visitors; the display of three-dimensional model can realize the interaction between visitors and cultural relics and enhance the attraction of museums. However, according to the current research, there are still some problems in the application of mobile AR technology: the display screen is not smooth due to the influence of software and hardware functions, the need for smartphone operation has limitations for the elderly [20], and it is difficult to repair the display equipment and files once damaged. In order to achieve better application of mobile AR technology, further research is needed.

6 Conclusion

This study designed a museum mobile AR system, realized the museum three-dimensional model display, and proved the high positioning accuracy and validity of the model display through the system test. It provides some ideas for the innovation of museum display form, which is conducive to improving museum visitors' visiting experience and enhancing museum cultural dissemination ability. This work also provide some references for the further application of mobile AR technology in museums. But due to various complex factors in the real environment of museum, AR system inevitably has some errors. In the future study, the intelligent mobile terminal needs to be further developed to further improve the positioning accuracy and tracking and registration accuracy of the system and study recognition of small cultural relics.

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