# Applications and Development of archaeological remote sensing Technology in China

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**Abstract:** Archaeological remote sensing is the archeological research using remote sensing data as data sources, and at present it is mainly used to investigate the distribution of archaeological sites and predict the existence of above ground or the underground ancient relics and their distribution pattern of detection, the space mapping of the ancient ruins, and the virtual recovery of ancient monuments and their background. Remote sensing technology is able to quickly and efficiently find the distribution of information of ground and underground ancient relics. It plays a significant role in the present archaeological research, and has increasingly become an essential process in large-scale archaeological investigation, especially pre-site inspection. Significant progress has been made in archaeological field investigation due to the rapid development of remote sensing technology, as well as the emerging of the new goals of archeology, the new needs and the applications of remote sensing technology. This article reviews the history of archaeological remote sensing, and introduces the advantages and roles of remote sensing technology in the detection of large-scale sites, and some research instances such as the current archaeological remote sensing and virtual archaeological research, and finally surveys the problems in the development of archaeological remote sensing.

**Key words:** remote sensing, archeology, grand site

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## 1 INTRODUCTION

China has a vast territory, and is the only ancient civilization in the world which has a continuous development history of over 5000 years, with many cultural heritages distributed throughout the country, especially those major sites which have great impact on China's politics, society, military and foreign relations, such as in the 2nd century BC the Silk Road opened up for spreading Chinese civilization to the world from the land and sea. Therefore, it is of great significance for the study of China and the whole history of human development to be fully aware of all kinds of information existed in these valuable cultural heritages.

As a study of the history of human development, archeology come into the world in the western country during the early 19th century, and was introduced into China in the early 20th century. With the development of natural sciences, archeology has developed into environmental archeology, remote sensing archeology, underwater archeology and other multi-disciplinary system from originally single subject. Particularly, by means of combining the humanities and social sciences and the natural science in the theory, methods and techniques, etc., remote sensing archeology extends the scale and depth in archaeological research. Earth observation technology mainly based on remote sensing technology, geographic information systems, global positioning systems and virtual reality technology has become important tools that help us to understand the temporal and spatial distribution pattern of cultural heritage, to reconstruct the development history of ancient civilization, to establish the cultural heritage information management system, and to realize a virtually recovering of ancient civilization.

## 2 DEVELOPMENT OF ARCHAEOLOGICAL REMOTE SENSING SCIENCE

In 1906 the British general H. P. Sharp used a hot-air balloon to take photograph of the late Neolithic Stonehenge sites in both vertical and slant ways. British geographer and archaeologist O. G. S. Crawford laid the foundation of archaeological aerial photography during the 1920s. He introduced the three marks in the aerial archaeological survey and aerial photo analysis: shadow marks, soils marks and vegetation marks, and identified the ancient Roman ruins from battlefields in the air photographs. A theoretical foundation for archaeological aerial photography was preliminarily established in 1930s, and many countries gradually applied the methods of archaeological aerial photography and got a large number of archaeological aerial

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photos. During World War II, aerial photography technology was further developed, and the vertical and slant photography technology were greatly improved, as well as color film and color infrared film were invented. Since then, archaeological aerial photography in Western Europe began to develop much more rapidly, especially reconstruction and economic development in the post-war when encountering sharp contradictions between economic development and historical heritage preservation, so the great importance was attached to archaeological aerial photography. Through the use of aerial photography and geophysical archaeological non-destructive detection technology, etc., the efforts of the archaeological exploration were strengthened and the cost of large-scale exploration operations was reduced.

In the short period of 15 years from the former Soviet Union satellite successfully launched in 1957 to the United States earth resources satellite which imaged the Earth in 1972, when space technology made a breakthrough in development, archaeological remote sensing opened a new chapter in getting earth observation data because of a large number of satellite platforms. Now we can acquire not only multi-spectral (or hyper-spectral), multi-angle, multi-resolution, multi-scale optical remote sensing data, but also multi-band, multi-polarization and multi-mode imaging radar data; not only the global-scale high-temporal resolution remote sensing images, but also high spatial resolution satellite imagery such as Quickbird with spatial resolution of 61cm. All of these provide a variety of data to the archaeological research including environmental archaeological, archaeological landscapes and cultural, paleoenvironment reconstruction, and also provide the basis for remote sensing image database to geographic information systems for ancient cultural resource management. Through remote sensing, geographic information systems, global positioning system with a combination of archaeological fieldwork, we can accurately extract the cultural heritage of human history, spatial information, and monitor the temporal and spatial variation of cultural heritage under the human and natural factors, in order to provide a scientific basis for the government departments in the protection of cultural heritage.

Virtual archeology was developed as a new computer-based technology in 1990's. With the virtual archaeological techniques, people can apply the historical records of cultural sites which have ever been suffered from damage, and combine with the topography, drainage, terrain elevation and other landscape features, to rehabilitate and reconstruct the original appearance of ancient sites, so as to provide historical data which can be archived into computer for heritage preservation.

Internationally, early in 1990 the international academic meeting "space archaeological study" was prepared by the French Space Agency, NASA, ESA, NASDA Group agencies and other remote sensing groups. In March 1997, the first "remote sensing archaeological application Conference" was held in Minnesota, the United States The conference discussed the satellite and aerial remote sensing in archeology, archaeological resource management, population and distribution patterns of archaeological and environmental studies to identify the advantages and the important role. In 2001 "Italy - United States Remote Sensing Symposium: the reconstruction of the ancient terrain with digital technology" was organized by the Italian Institute for Cultural Heritage applications and the United States Boston University Archaeological Research Center, Center for Remote Sensing and archaeology department in cooperation with NASA. The symposium mainly aimed at GIS, spatial analysis and remote sensing technologies for the reconstruction of the ancient terrain, as well as evaluated and displayed the archaeological landscape as an important and various cultural resources. In April 2002, the international conference "computer applications and quantitative methods in archeology" was held in Greece under the theme of "archaeology and digital heritage". The conference discussed the unique function of space information technology in the archaeological application fields, and evaluated and analyzed the results achieved in the World Heritage's monitoring, management, mapping, and protection with the spatial information. These reflected that the archeological development with themes of digitalization became the mainstream in the development of interdiscipline. Remote sensing and virtual reality technology have become the main research techniques in archaeology and ancient sites protection.

In comparison with the Western countries, China's development in archaeological aerial photography began late. During the period of the 7$^{th}$ Five-Year Plan, China carried out an archaeological aerial photography for the ancient city of Shouchun in Anhui Province, and the Museum of Chinese History set up an Archaeological Center for Remote Sensing and Aerial Photography. And then they made an aerial photography in Yanshi Erlitou Ruins in Henan Province, rural ditch Yanshi Mall body sites, Luoyang, capital of the Sui and Tang site of the south east and so on. The Shandong Institute of Cultural Relics and Archeology, in cooperation with Prehistoric Archaeological Research Department of Ruhr University in Germany, analyzed the aerial photos located in Linzi County in Shandong Province, acquired by the U.S. military in 1920s—1930s, and mapped the ancient tombs throughout the city and their location, as well as published the first report of archaeological aerial photography. In 2002 China developed another archaeological remote sensing work in northern Shaanxi Tongwancheng and Inner Mongolia part of the ancient sites and Shanhaiguan Great Wall, Mutianyu, Zunyi Hailongtun. In 2006, the "Applications of Spatial Information Technology in the great site protection" project, supported by the Ministry of Science and Technology, was launched to make a comprehensive study on the present situation and the history of the evolution of the Grand Canal of China.

In 1993, Archaeological Remote Sensing of Urban and Environmental Laboratory was approved by the Ministry of Education, set up at East China Normal University, which has been making research on remote sensing archaeology in the lower

reaches of the Yangtze River, Silk Road, the Great Wall, the Central Plains and other areas, and made remarkable achievements (Liu, 1998). The Institute of Geography, Henan Academy of Sciences investigated into the application and experimental study with photogrammetry, photo interpretation of ancient cultural relics and other work in archaeological sites through the combination of remote sensing technology and the archaeological department. Chinese Academy of Social Sciences used archaeological aerial images, satellite images, as well as shallow geophysical methods (ground penetrating radar, etc.) to find the archaeological sites and applied high-resolution non-destructive detection for archaeological relics, providing a reliable basis for the archaeological excavation and research. And at the same time they developed the projects of "high-resolution geophysics and satellite remote sensing in archaeological resource assessment of the integration of research" and "the remote sensing of archaeological and geophysical prospecting for Huaibei Shangcheng in Anyang city". The Former Center for Aerogeophysical Survey and Remote Sensing of State Department of Geology and Mineral Resources carried out an observation on the entire territory of the ancient Great Wall in Ningxia and Beijing, and finished the aerial photogrammetric work and analysis of photography. Anhui Normal University and Anhui Center for Geological Remote Sensing made an archaeological remote sensing research in the Grand Canal of China. Institute of Remote Sensing Applications, Chinese Academy of Sciences, detected the ancient Great Wall buried by dry sand, located at the junction of Shaanxi province and Ningxia Autonomous Region with the shuttle imaging radar data, and additionally delineated the "anomaly" of the Beijing Laoshan Tomb of Han Dynasty with high-resolution camera.

Given the domestic demand for archaeological remote sensing, "Archaeological Remote sensing Laboratory Jointly Sponsored by Chinese Academy of Sciences, Ministry of Education, the State Bureau of Cultural Relics" was set up in November 2001 in Beijing, and the official archaeological remote sensing workstations were established in Zhejiang, Henan, Anhui, Shaanxi, Jiangsu, Inner Mongolia, Yunnan province, respectively. This cross-sector, cross-industry Joint Laboratory of Remote Sensing Archeology takes national needs as the goal, through a broad network of cooperation with local archaeologists and remote sensing departments aiming at promoting the development of archaeological remote sensing. The first national conference on remote sensing archeology was held in Beijing by remote sensing archaeological laboratory in December 2002; "the space awareness of the cultural heritage of mankind" Xiangshan Science symposium was held in 2003; Beijing International Conference on Remote Sensing Archeology held in 2004 made the exchange of spatial information into the application of archaeological scene. In April 14, 2005, China and UNESCO signed an agreement at UNESCO headquarters and the content was China will join the open initiative action, which was designed to use space technology to assist in the protection of world cultural heritage. Archaeological Remote Sensing Laboratory Jointly Sponsored by Chinese Academy of Sciences, Ministry of Education, and the State Bureau of Cultural Relics will work with the Argentine Space Agency, the Canadian Space Agency, and the Lebanese Center for Remote Sensing, Morocco Royal Center for Remote Sensing and NASA together to assist the United Nations UNESCO World Heritage monitoring by satellite.

## 3 ADVANTAGES AND ROLES OF REMOTE SENSING TECHNOLOGY IN DETECTION OF GREAT SITE

### 3.1 Advantages of remote sensing technology in detection of great site

Compared with traditional archaeological fieldwork, archaeological remote sensing can get a large amount of information, which can not be acquired from the ground-based observations in detection of great sites. The main advantages as follows (Yin & Wang, 2003; Zhao, 2004).

*3.1.1 Large scale covering*

Remote sensing can access global information on the study area, especially like China's Great Wall and the Grand Canal, the Silk Road and other lager sites. But ground-based observations can only get a view of the features within the landscape, and can not constitute the overall image. The imaging scale of Remote sensing image has a large range from the Moderate Resolution Imaging Spectrometer and low-resolution scan mode synthetic aperture radar(SAR) obtaining the small-scale regional images, to Quickbird and IKONOS high-resolution remote sensing image for studying the ancient sites in detail.

*3.1.2 Large spectral range*

People can observe by naked eyes only the visible part of the electromagnetic wave, but remote sensing (including geophysical prospecting techniques) is able to observe and record wide range of spectrum range from the ultraviolet, visible, infrared, thermal infrared, microwave, etc., to the whole range of energy-band electromagnetic waves to detect surface features.

*3.1.3 High spatial and temporal resolution*

Archaeological fieldwork can only survey the archaeological objects at specified time on the field, but archaeological remote sensing could be used to repeat observations in the high temporal frequency and accumulated the obtained satellite remote sensing data in the study area, to study the archaeological sites, the terrain landscape and the ancient sites with changes over time. In the case of spatial resolution, the high-resolution commercial satellite is able to provide multi-band remote sensing images compared to the images obtained by aerial photogrammetry.

*3.1.4 High spectral resolution*

Multi-spectral remote sensing images can provide different spectral remote sensing information in the same study area, and hyperspectral imager can subdivide from a few dozen to hundreds of sub-bands within a specific spectral range, enhancing

the ability of features (such as crops changes in archaeological study area) recognition.

*3.1.5 Penetrating ability*

Synthetic aperture radar (SAR) imaging has the properties of penetrating, which can be used for studies of paleoenvironment in arid desert area. And more importantly using ground- penetrating radar technology can obtain the archaeological information in a certain depth under the surface.

*3.1.6 Non-destructive detection for archaeological sites*

With the advantages of non-destructive detection on the archaeological objects of remote sensing archaeology, using geophysical methods to detect and study the characteristics of sites of shape and pattern of the structure, we do not have to dig large areas, which can save lots of manpower, material and time without any damage to the sites.

## 3.2 Roles of remote sensing technology to detect the archaeological sites

*3.2.1 Important discoveries of sites using remote sensing technology*

As the ancient ruins preserved in the surface or under the surface gradually fell into disrepair and loss with the years, some have been turned into farmland, or villages and towns. However, because all these relics were artifically built, there is a difference between these relics and the soil environment around these relics which has not been disturbed by human, which formed a set of special signs on the soil, moisture, surface temperature in the region. Although we can not find even a little special features observed on the ground, these differences would caused spectral differences in the remote sensing images, so these ancient sites can be identified.

In addition, radar has capability of observing and imaging throughout the day, all-weather and penetrating some features under the surface; therefore, the ancient site can be identified from the radar images because of the backscattering characteristics determined by their features. So far, there are many instances of finding ancient sites by using remote sensing technology, which fully reflect the role of remote sensing in the archeological application. Archaeologists in the United States have found ancient Egyptian and renowned Alexandria which have long been sunk at the seabed for a few thousand years by means of satellite remote sensing images. Europe discovered a number of architectural monuments of ancient Rome and the famous “Roman Road” based on early photographs of archaeologists. Scientists in NASA Ames Research Center used remote sensing technology to open the secrets about the Boom Rise and Fall of the Mayan civilization, and successfully identified the characteristics of the ancient Mayan ruins. Greek archaeologists found the ancient city “Helike” in the Collins Bay destroyed by an earthquake in BC 373 by using infrared photograph. NASA archaeologist identified the ancient path in Costa Rica forests from color infrared aerial photographs. In 1994 the SIR-C/X-SAR and AIRSAR imaging radar were made research on the ancient city Angkor in Cambodia surrounded with the thick forest. The distribution of the ancient city Angkor was reconstructed, which expended from original 200—400km$^2$ to 1,000km$^2$, and the Grand Canal water system was redrawn, so that we know the original appearance of the spectacular ancient city Angkor which has already been dead.

*3.2.2 The advantages of remote sensing technology in Large-scale sites investigation, protection and monitoring*

China’s cultural relics distribute all around the country, including 38 World Heritages, and a large number of the ancient sites needing to be identified and protected, such as large-scale ancient villages, cities, imperial tombs, canals, the Great Wall, Silk Road. China has more than 1200 state-level key Cultural Relic protection units and 99 national historic renowned cities. It is no doubt that remote sensing technology would be an effective means to explore the ancient sites, and dynamically monitor the changes in historical and cultural sites and ancient ruins. Taking the Great Wall as an example, the entire length of Great Wall is more than 7000 km ranging from Dandong Hushan to Jiayuguan. The ecological environment along the Great Wall became gradually deteriorated, and the Great Wall often suffered from kinds of severe damage due to human factors, especially in the western arid desert area, where the majority of the Great Wall were buried in sand. At present, less than one-third of the Great Wall has been well restored and protected, and another one-third is incomplete, as well as the-third did not exist long before. Therefore, it is important to ascertain the distribution of the Great Wall by and better protect the Great Wall by using remote sensing techniques. Silk Road was a main way to exchange China’s culture with the West, and many Chinese and foreign cultural relics were left on this road, such as the ancient cities Niya, Loulan in China, and the ancient city Merv in Turkmenistan Central Asia. Silk Road archaeological remote sensing was an important issue when the shuttle imaging radar passed by China’s ancient city Niya in 1994, and researchers from Canada and other countries carried on a multi-disciplinary archaeological remote sensing investigation into the city Merv that was ever an oasis. They used GPS technology and IKONOS images of the ancient city to locate precisely and analyze ancient ruins. In addition, recently, scientists in China made several remote sensing archaeology researches on the Qin Shi Huang Mausoleum, Sanxingdui, and the Grand Canal. In summary, people may have a better understanding on cultural sites by this work.

*3.2.3 Paleoenvironment research with spatial information application*

The restoration of the ancient environment played a significant role for the study of social, cultural, economic, natural and geographical conditions, etc. And the changes of palaeoenvironment were also important to research about the ancient environment and political evolution. Using remote sensing to study the long period changes of environmental history mainly depended on these “signs” showed on remote sensing images to be identified. Due to a variety of research subjects have their own characteristics which were different from each other, many

of which got reserved in different degree. These characteristics were reflected in the remote sensing images, and you could identify them by the differences from the color, shadow, shape, size, texture, etc. (Liu & Wang, 2006; Wan & Zhou, 2007).

Currently, the application of remote sensing techniques for environmental archeology, mainly focused on the use of multi-temporal, multi-source and multi-resolution airborne and space remote sensing images to monitor environment of archaeological sites, landscape archeology, environmental change and relationship research of social transformation and historical periods environmental restoration.

The space shuttle Columbia that carrying the SIR-A radar flight in the eastern Sahara Desert in November 1981, and McCauley *et al*. studied the radar echo on the SIR-A images from bedrock under the sand, which revealed an ancient river several meters below the sand layer. The study showed that: the northern part of Africa had a much larger stream system than today's Nile river, which denied the deduction that there was no trunk stream of water system. The paleochannel provided an oasis in the desert for Paleolithic humans, and showed the environmental conditions at that time in the Sahara desert. Combining multi-source satellite remote sensing data and validating the data by field work in Xinjiang at several times, researchers from the Institute of Remote Sensing Applications, Chinese Academy of Sciences, revealed the existence of ancient water system in the region. They found that sand path flow from the southwest to the northeast and then into the Yamaleike desert. Using the old aerial photo taken in the 1950s, the watershed tanks of the Grand Canal was discovered, which disappeared in Nanwang, Jining, Shandong province, and the work provided important reference for the protection and arrangement of the heritage sites.

*3.2.4 Non-destructive detection to underground sites*

Another study in remote sensing archaeology is the non-destructive detection of archaeological sites buried under the ground. Current non-destructive detection methods include magnetic detection, resistance probe method, microwave pulses "ground-penetrating radar" as well as seismic detection, etc.

China starts this work very late, and the main results contain the detection of "Yin mountain large tomb" located in Shaoxing, Zhejiang province with ground-penetrating radar by East China Normal University.The First Qin Emperor Mausoleum was explored using more than 20 advanced high-precision physics detection technology such as the airborne remote sensing hyperspectral technology, thermal infrared remote sensing technology, magnetic technology and electrical technology. The First Qin Emperor hill covered 2.13 $km^2$.

Internationally, Israel expert made use of thermal infrared sensor in the 1333m altitude of the Golan Heights, and succeeded in detecting the archaeological sites buried under the soil and mapping with thermal infrared. This is the first archaeological work with thermal infrared remote sensing.

*3.2.5 Archaeological thematic mapping and Cultural Relics information system*

The main tool for remote sensing archaeology are remote sensing images, because image itself can be preserved for long time. We can discover the damaged relics on the previously archived remote sensing image, discover the current relics in the current image, and make the archaeological information thematic map. The location, region and true appearance features of these relics could be stored for future analysis.

After geometric correction, remote sensing images have very high accuracy, and we can directly measure the area and shape of the archaeological sites. Besides, we can directly draw these results onto the map, so this will be very meaningful.

At present, internationally, using remote sensing for archaeological mapping is the main part of archaeological remote sensing, and is developing rapidly and widely. Especially, high-resolution satellite images and aerial photographs are the main data source of the large-scale mapping. Remote sensing and GIS technology are applied to survey large-scale site and position precisely, to provide environmental monitoring, site positioning, and forecasting purposes for future.

There are a variety of applications with GIS in archaeological research. GIS can be applied to data collection and storage, analysis, interpretation and expression. Specifically, it can be summarized as the following aspects: establishing the archaeological information management system, establishing prediction model of archaeological sites, development and expansion of archaeological sites, landscape archaeological GIS research, etc.

*3.2.6 Space technology and ancient human remains and environmental reconstruction*

Since the 1990s, there has been a virtual heritage (or virtual archaeological) technology, which refers to the use of advanced computer technology applied to do research on world history, culture, natural heritage protection and development. Virtual reality technology is a key technology for the development of its application.

Virtual reality is selected as the technical support to research on virtual heritage, because the information what the virtual heritage want to express is multidimensional, not only historical authenticity, but also a cultural art, and the reality of the environment. And according to the current computer technology, it is necessary for the expression of multi-dimensional information to provide high-performance hardware of virtual reality technology to support. Studying virtual heritage also involves other types of computer technology, such as the scanning technology, information processing, computer-aided design, geographic information systems, etc. The selection of technologies in specific applications should depend on the research project. From the concept, virtual heritage is to emphasize the cultural realities of history that we will express, so it reflected the efforts made to create science and art and continuous upgrading knowledge, beliefs and values experience in the development of human. Virtual heritage is the new direction of development and trends to foreign history heritage protection and more and

more people are engaged in studying this field. China is a country with a long history of ancient civilization, and its rich historical and cultural heritages of the history have become an important part of cultural heritage of the world. Virtual heritage studies can promote heritage conservation and development of China's historical and cultural heritage, and adapt to the trend of development of the world. At the same time it is of great significance for improving China's status in the world historical and cultural heritage.

Virtual heritage technology can be used in reconstruction of historical and cultural sites. Demonstration of the British Museum's ancient Greek temples, the ancient Roman castle shown in the Los Angeles Museum of the United States, are based on defective parts to "repair" and simulate. The Digital Dunhuang Grottoes and the digital Imperial Palace were put into practice. American scholar resume virtually the place of New Mexico Indian indigenous people. Egypt scholars also conducted a virtual simulation with a large pyramid in different angles. Japanese scholars simulated the historical site located in Pengtou mountain, Hunan Province, China, during the rice culture 7000 years ago with virtual reality technology combining with spatial information, represented the scene of urban layout. We can also use virtual technology to restore the original appearance of the disappeared city (such as the ancient Loulan city, the Grand Canal and the ancient river channels), and simulate the current sites with virtual reality at the same time, in order to provide a valuable electronic data for heritage sector.

## 4 EXAMPLES OF WORK ON ARCHAEOLOGICAL REMOTE SENSING

In recent years, with the growth of China's economic strength and the improvement of application level of remote sensing technology, the field of application of remote sensing being broadened and national emphasis on remote sensing archaeology, archaeological remote sensing technology in China has improved continuously, and remote sensing technology in archaeological sector has more and more been put into practice and achieved a great deal of research results. The following is the examples and part of results obtained by the Joint Laboratory of Archaeological Remote Sensing in recent years.

### 4.1 Remote sensing archaeology

#### *4.1.1 Grand Canal of China*

Grand Canal of China, as a great works created by the Chinese ancient people, is a valuable cultural heritage left to the world by Chinese nation. In recent years, the plan that Grand Canal of China applies for world cultural heritage has been made under the efforts from cultural relics departments, relevant experts and others. As a result of the large-span of the canal, as well as the diversity of the cultural heritage of the canal, remote sensing technology was applied first of all to the Grand Canal of 1794 km, and the research was developed on the surrounding environment today and historical evolution, in order to provide a scientific basis for making a protection plan.

The changes of the canal and the canal citie's environment within the 60 years can be drawn by processing and analyzing different time, different-resolution remote sensing images. Fig. 1 shows the areas flowed through by the Grand Canal and distribution of SPOT5 data acquisition, Fig. 2, Fig. 3 and Fig. 4 show the effect of the three regions along the canal route compared air photos with satellite images.

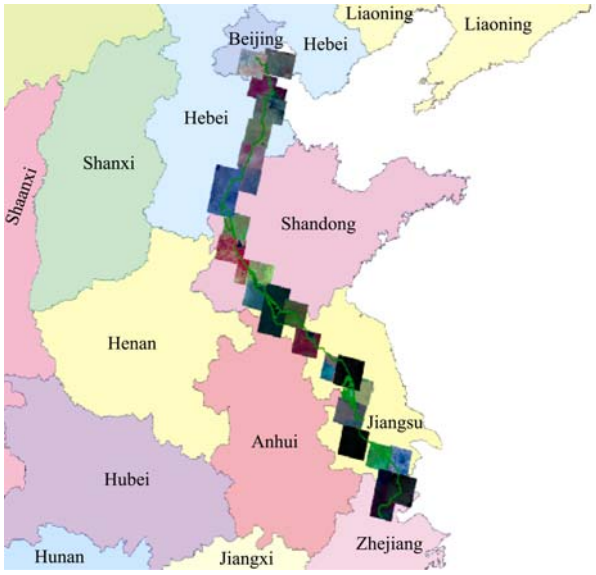



Fig. 1 SPOT5 images distribution along the Grand Canal of China

#### *4.1.2 Great Wall*

China's Great Wall is one of the greatest works in the history of human civilization. It was built more than 2000 years ago during the Spring Autumn Dynasty, War Times Dynasty, and the Qin Dynasty after the unification of China. Han and Ming Dynasties also made large-scale construction.

People wanted to know the specific length, location and spatial distribution of the Great Wall for a long time. However, due to the span of the Great Wall's distribution, the complex topography, and even burying in some areas, it is difficult to arrive at a unified conclusion about these information. Therefore, State Administration of Cultural Heritage planed to apply remote sensing technology to conduct a comprehensive survey on the Great Wall. Prior to this, China's science and technology workers also made use of remote sensing to detect and explore the Great Wall's distribution, of which the excellent work is done by Guo H D (1997), who used multi-band, full-polarization imaging radar SIR-C to identify the ancient Great Wall buried in dry sand in Sui and Ming dynasties located at the junction of Ningxia and Shaanxi province (Fig.5), as well as analyzed the changes of environment and identify Shanhaiguan old dragon head of the Great Wall with high-resolution remote sensing image QUICKBIRD and other images (Fig. 6).

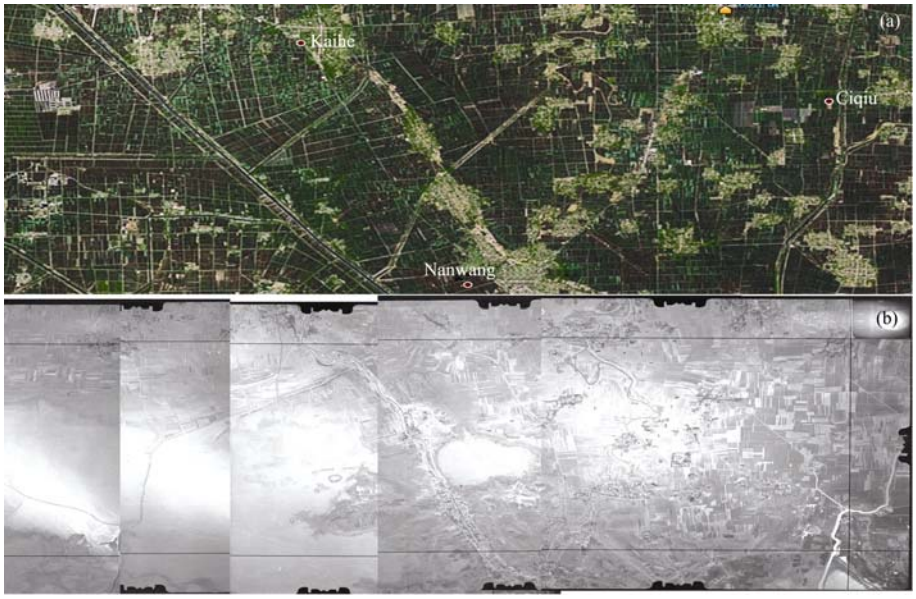



Fig. 2 Shandong Jining Nanwang - watershed project of Beijing-Hangzhou Grand Canal
(a) Remote sensing image in 2005, showing the resevoirs disappeared into fields; (b) Aerial photo map taken in 1954, showing the existence of the resevoirs

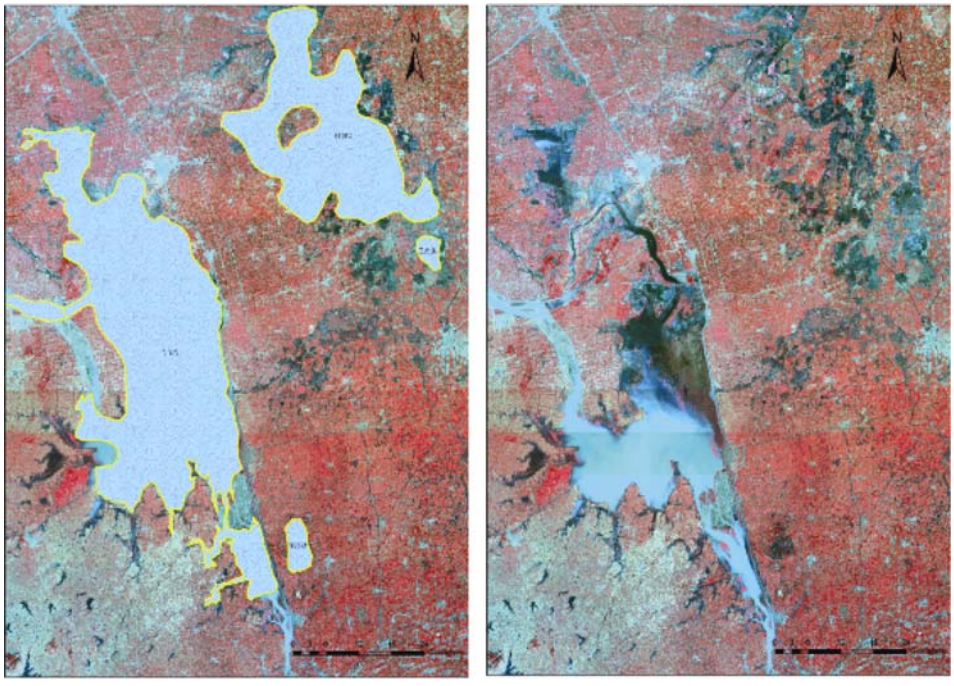
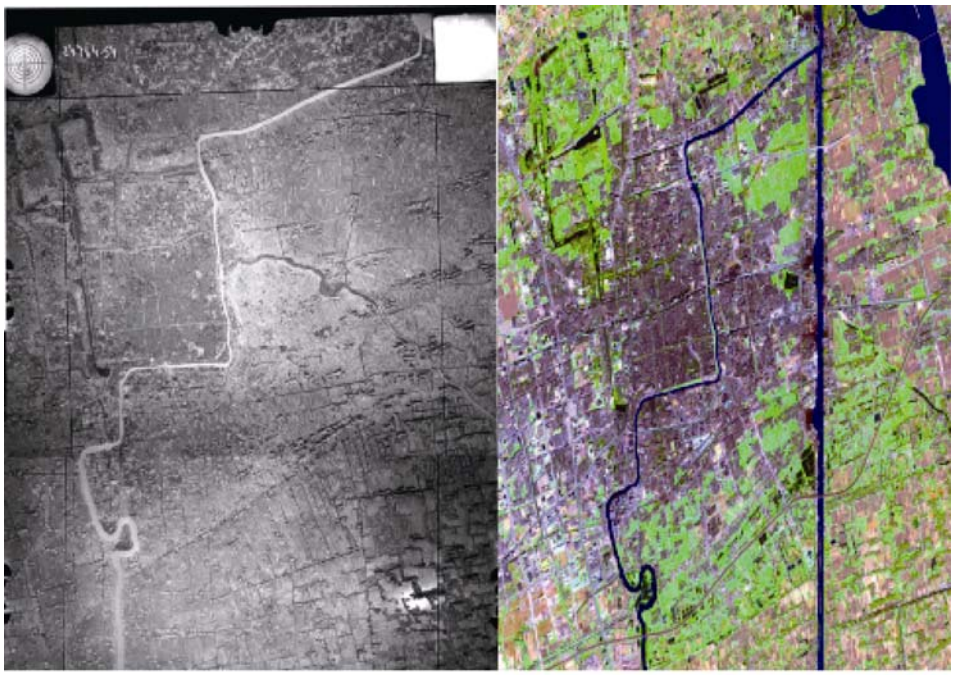



Fig. 3 The changes of Gaoyou Lake, Sheyang Lake along the canal in different periods
(a) 100 years before 2005; (b) 2005

*4.1.3 Archaeological Sites of Ancient City in Inner Mongolia*

There are various cultural sites in Inner Mongolia, but Inner Mongolia has the vast territory and many sites are located in desert, grassland, and no man's land. With ground survey methods to investigate these sites, it is much difficult to achieve a well comprehensive investigated effect throughout the Inner Mongolia. In 2002, by use of Lanying AD-200 light aircraft manufactured by Beijing Keyuan Light Aircraft Industrial Co., Ltd, the sites located in the central and northern Shaanxi, Inner Mongolia Autonomous Region were observed and investigated, and good results were achieved. The aircraft structure is relatively simple with small size and light weight, so it can facilitate rapid disassembly, and you can transport it with ordinary trucks. At the same time, the requirements of flying and landing is pretty low that it can be operated on roads or flat grass, etc. Besides, it requires relatively short runway. Therefore, using such plane brought great convenience to investigate the sites. Fig. 7 (a) is the AD-200 light aircraft, Fig. 7 (b), Fig. 7 (c) is the photography taken by aerial digital camera in 2002, and a group of Juyan sites was found in Inner Mongolia. AD-200



(a) (b)

Fig. 4 The changing information of canal and city within 60 years
(a) Yangzhou in 1950s; (b) Yangzhou today, the area of city expand 60 times than before

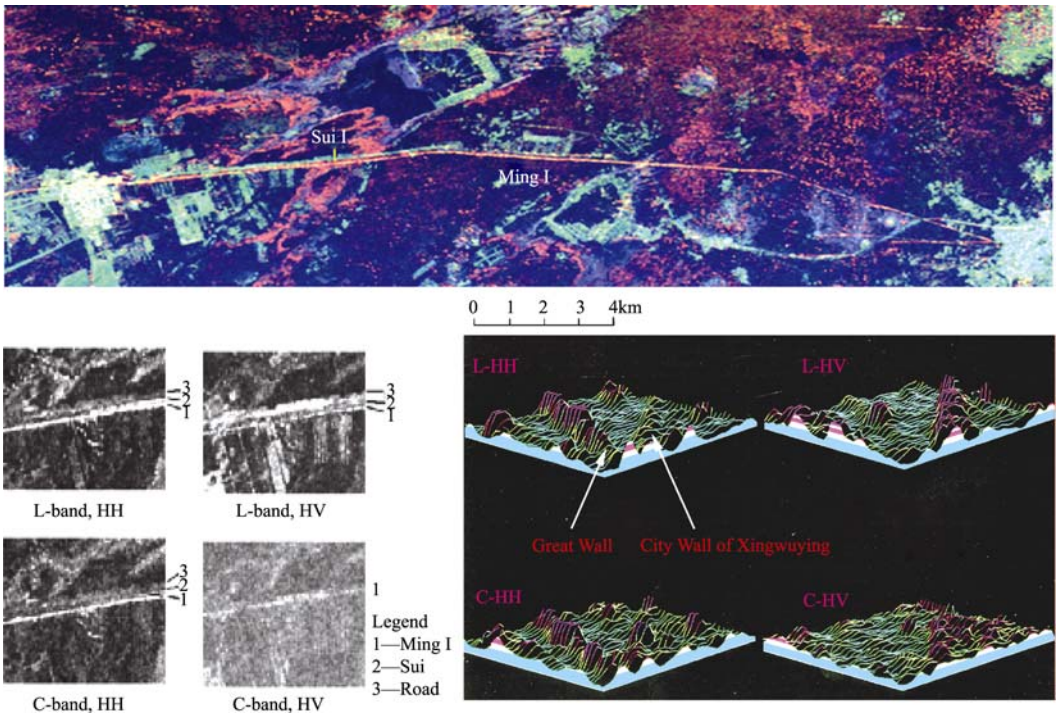



Fig. 5 Great Wall of the Sui, Ming Dynasties buried in dry sand detected in Shaanxi and Ningxia Yanchi region, with multi-band and multi-polarization SIR-C radar and various combinations with different polarization show the different effects

light aircraft in the aerial survey in Inner Mongolia found the Great Wall, the Qin Straight Road and other new sites of the ancient city (Fig. 8) and Wei gucheng Yuning site in 2005 (Fig. 9).

### 4.2 Virtual reality

Through the combination of spatial information technology and VR technology, the spatial geographic information of the large-scale ancient sites and visualization expression of cultural information in various environment, network and integration management were realized. This technology provides a much more natural, convenient and efficient tool to express spatial information. The platform “large sites virtual reality system” which has the characteristic of three-dimensional dynamic,

Fig. 6 Shanhai guan Great Wall old dragon head in QUICKBIRD image


Fig. 7 AD-200 light plane and groups of sites in Inner Mongolia Juyan photoed by airborne digital camera

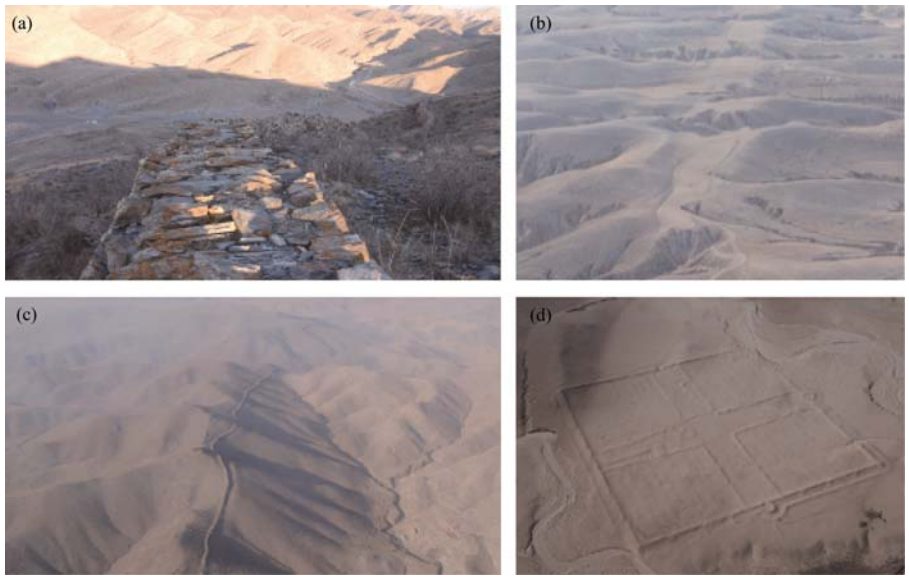



Fig. 8 The new sites in Inner Mongolia found by AD-200 light plane in 2005
(a) and (c) Great Wall; (b) Qing straight road; (d) unnamed Great Wall

Fig. 9 Yuning gucheng in Inner Mongolia

real-time interactive inquiries and integration of the information from the cultural heritage management and archaeological excavations was built. It further expanded the fields of management of archaeology and cultural heritage studies. With the help of virtual reality, it is realized that fully sharing and rationally utilizing the archaeological cultural information resources and sustainable development.

Several works in using virtual reality technology to protect large archaeological sites as following:

(1) Virtual reality technology for large archaeological sites. We have completed the research work about three-dimensional information acquisition methods and data structures, etc. In large archaeological sites, three-dimensional visualization process of a large-scale digital terrain has been realized; simulation methods of the evolution process of a great site have been studied, researches on generation of dynamic body of water have been carried out.

(2) The development of three-dimensional simulation of the scene: such as virtual reality scenario of Beijing's Tongzhou, Shandong' Nanwang, the ancient city of Yangzhou (Fig. 10, Fig. 11). We have achieved a single version of the multi-level integration and management scene. A network of three-dimensional scenes of the Active X control can be achieved in small three-dimensional Web browser scene.

(3) The Server/Client system was developed based on Microsoft DNA, and the Server/Client program to view three-dimensional information, which is being tested.

(4) Integration and hierarchical block processing of ETM,

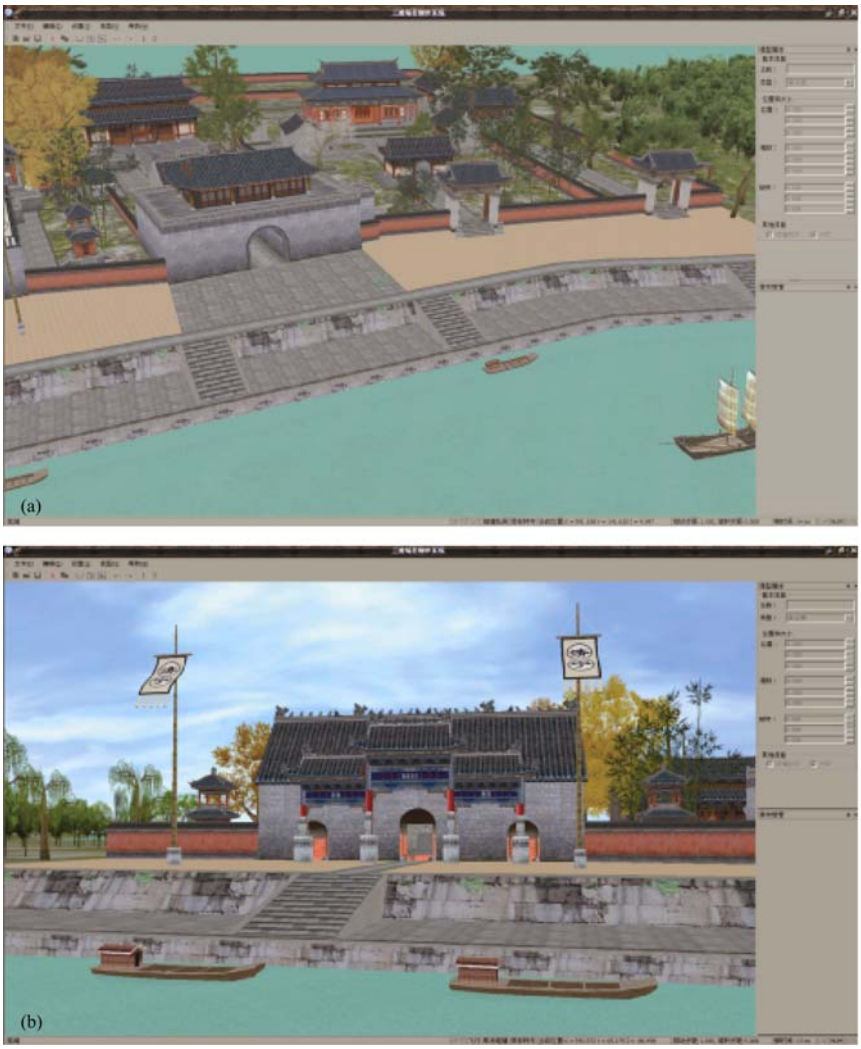



Fig. 10 The recovered working sketch for the water control pivot in Nanwang, Shandong Province

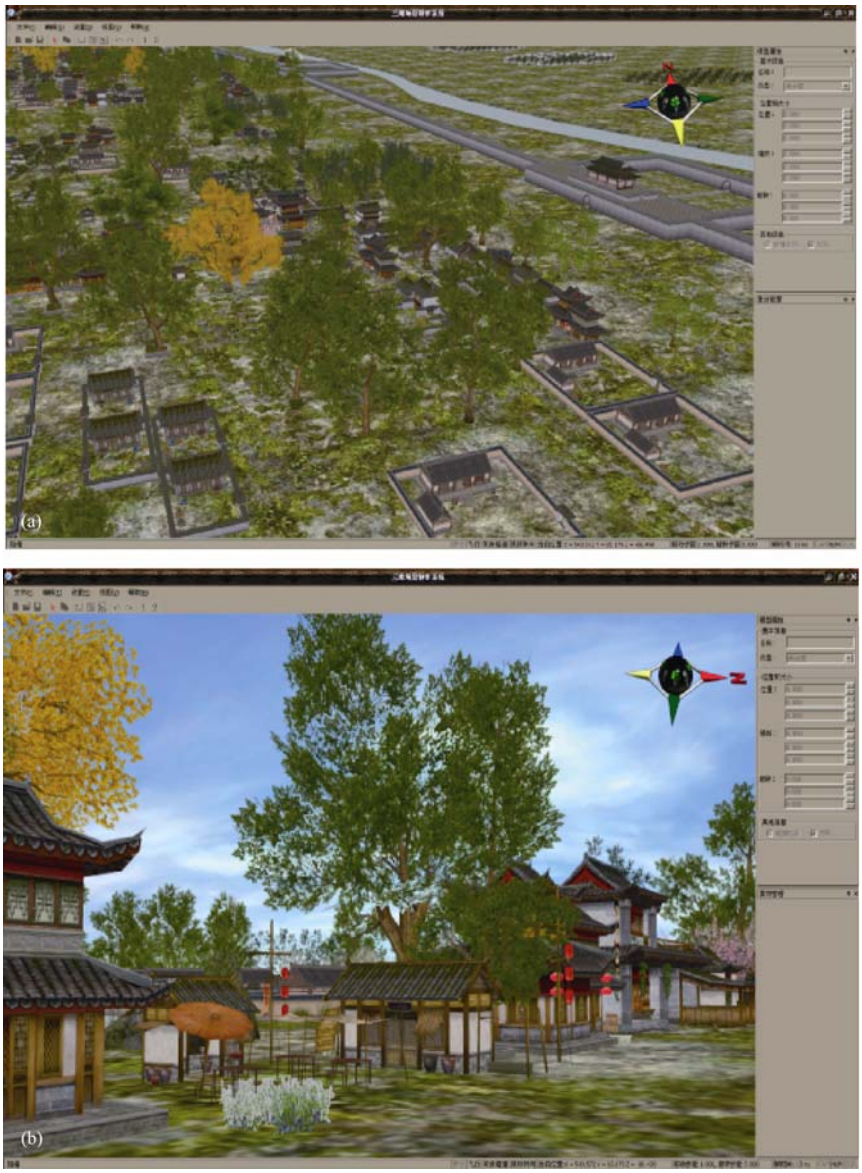



Fig. 11 The recovered landscape along Yangzhou section of the Grand Canal and its surrounding ancient buildings, in reference to the Yangzhou City in Tang Dynasty

SPOT5 data have been made. The 1∶250,000, 1∶50,000 DEM model were finished. The virtual reality visualization system has been established to combine with the remote sensing images covering the entire canal and relative China's eastern region.

## 5 SOME PROBLEMS FACED BY REMOTE SENSING TECHNOLOGY IN THE STUDY OF HISTORICAL SITES PROTECTION

Remote sensing technology with its unique advantages plays an increasingly important role in the detection and protection of large sites. However, there is still a gap when compared with other application fields.

(1) Archaeological remote sensing is the mutual penetration science of natural and social sciences. It requires that remote sensing scientists must have the technical knowledge and the history archaeological knowledge.

(2) The complexity and diversity from the natural environment, particularly strong noise in the human activity areas, will bring much difficulty to extract useful remote sensing information in the archaeological sites.

(3) The archaeological sites in different times, different areas, even in the same time, the same area, are different from the structure to the material composition. And the relevant theoretical researches such as the mechanism of the interaction between electromagnetic waves with the sites still need more work.

(4) The existence condition of most large-scale ancient ruins is semi-buried or buried. How to extract information from the complex weak features is the key technology problem to solve at present.

(5) Remote sensing archaeology is a cross-subjects and in-

terdisciplinary science. In the study of archaeological sites, it is necessary for remote sensing scientists to integrate the knowledge of archeology, environment, geophysical exploration, drilling and other means and methods.

Remote sensing technology has demonstrated great application potential in the study of sites. With the continuous development and improvement of remote sensing technology and the deepening of archaeological research with archaeological remote sensing, like other applications, remote sensing will be continuously improved and upgraded in the application in archaeological work, and contribute to the exploration of the origin of the Chinese civilization and the protection of important sites.

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# 中国遥感技术在考古中的应用与发展

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摘 要: 遥感技术的日新月异以及考古学的新目标、新需要不断出现, 利用遥感技术进行田野考古研究的工作已经取得长足进展。回顾了遥感考古的历史, 介绍了遥感技术在大遗址探测中的优势与作用, 以当前遥感考古与虚拟考古研究为例, 对遥感考古发展中面临的问题进行了概述。

关键词: 遥感, 考古, 大遗址

中图分类号: TP79 文献标识码: A

## 1 引 言

中国幅员辽阔, 是世界上惟一有着 5000 年连续发展历史的文明古国, 文化遗产遍布全国各地, 特别是影响中国政治、社会、军事和对外交往的大型遗址, 如公元前 2 世纪开辟的丝绸之路从陆地和海洋把中华文明传播到世界各地。因此, 充分认识这些宝贵文化遗产的各种信息, 对研究中国和整个人类发展历史具有重大意义。

作为研究人类发展历史的考古学, 19 世纪初在西方诞生, 20 世纪初传入中国, 随着自然科学的发展, 已从单一的考古学发展成为环境考古学、遥感考古学、水下考古学等多学科体系, 展现出考古学蓬勃发展的轨迹, 特别是通过人文社会科学与自然科学在理论、方法、技术手段等方面的结合, 丰富了考古学研究的广度和深度。以遥感技术为主, 对地观测技术、地理信息系统、全球卫星定位系统和虚拟现实技术已成为认识文化遗产的时空分布规律, 重建古文明发展史, 建立文化遗产信息管理系统, 再现古文明空间的重要手段。

## 2 遥感考古科学的发展

1906 年英国军官 H. P. 沙普从军用热气球上对新石器晚期的巨石阵遗址进行了倾斜和垂直摄影拍照。英国地理及考古学家 O. G. S.克老福德(Crawford)在 20 世纪 20 年代作的工作奠定了航空摄影考古学的基础, 提出了航空考古勘察和航片分析的 3 种标志: 阴影标志、土壤标志和植被标志, 从航空像片上识别出农田里罗马时期的古城遗迹, 到了 20 世纪 30 年代基本建立了航空摄影考古学的理论基础, 许多国家逐渐应用航空摄影考古学的方法并拍摄了大量的考古航空像片。第二次世界大战期间, 航空摄影技术得到了进一步的发展, 在垂直和倾斜摄影技术上得到了很大的提高, 研制出彩色胶片和红外假彩色胶片。此后, 航空摄影考古学在西欧得到更迅速的发展, 特别是战后重建和发展经济的过程中遇到经济建设与文物保护的突出的尖锐矛盾, 航空摄影考古受到极大地重视。通过利用航空摄影考古和地球物理无损探测等技术, 加强了考古勘探的力度并降低了大面积作业的勘探成本。

自 1957 年前苏联人造卫星的发射成功到 1972 年美国地球资源卫星对地球成像, 在短短的十几年里, 人类航天技术得到了突破性的发展, 从卫星平台上获取大量对地观测数据, 揭开了遥感考古的新篇章。现在我们不仅能得到多光谱(甚至高光谱)、多角度、多分辨率、多尺度的光学遥感数据, 还能得到多波段、多极化、多模式的成像雷达数据; 不仅能得到全球尺度高时间分辨率的遥感影像, 还能得到像 Quickbird 这样 61cm 高空间分辨率卫星图像。

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所有这些为包括环境考古、文化景观考古、古地理重建等在内的考古学研究提供丰富的数据，也为用地理信息系统对古遗址的文化资源管理提供基础遥感影像数据库。通过遥感、地理信息系统、全球定位系统与田野考古的结合，我们能精确地提取人类历史文化遗产的空间信息，并监测文化遗产地在人类和自然因素作用下的时空变化，为政府部门保护文化遗产提供科学依据。

虚拟考古是 20 世纪 90 年代发展起来的一项基于计算机平台的新技术。利用虚拟考古技术，人们可以通过基于过去曾遭受破坏的某个文化遗址的历史资料，结合该地的地貌、水系、地形高程等景观特征，恢复和重建古遗址原貌，为文物保护提供一份可用计算机存档的历史资料。

国际上, 1990 年初由法国空间局、美国宇航局、欧空局、日本宇宙事业开发集团等遥感机构共同筹备了“ 空间考古研究 ”的国际学术会议；1997 年 3 月，第一届“ 遥感考古应用会议 ”在美国的明尼苏达州举行，会议讨论了卫星和航空遥感在考古、考古资源管理、居民地分布格局识别及环境考古研究中的优势及重要作用；2001 年由意大利文化遗产应用技术研究所和美国波士顿大学考古研究中心、遥感中心和考古系与 NASA 合作举办了“ 意大利–美国遥感研讨会：数字技术重建古地形 ”，主要目的是针对 GIS、空间分析和遥感技术开展古地形重建，以及把考古景观作为重要且丰富的文化资源进行评价和展示。2002 年 4 月，在希腊召开了“ 考古学中计算机应用和定量方法大会 ”，其会议主题为“ 考古的数字遗产 ”，讨论了空间信息技术在考古领域上的独特作用，评价和分析了空间信息在世界遗产的监测、管理、制图、保护等方面取得的成果。这些都反映出以“ 数字化 ”为主题的考古学发展已成为当今多学科交叉发展的主流，遥感和虚拟现实技术已成为考古研究和古遗址保护与重建的主要技术手段。

中国航空摄影考古的发展相对于西方国家，起步较晚。“ 七五 ”期间，在安徽开展了对战国晚期“ 寿春古城 ”的航空摄影考古工作，1996 年在中国历史博物馆成立了遥感与航空摄影考古中心。此后开展了对河南省偃师二里头遗址、偃师尸乡沟商城遗址、洛阳隋唐东都城遗址南部等航空摄影；由山东省文物考古研究所与德国鲁尔大学史前考古学研究室合作，对 20 世纪二三十年代美军所摄山东省临淄县境内的航片进行室内观察分析，并制成临淄全境古城与古墓位置地图，出版了中国第一部航空摄影考古报告；2002 年开展了对陕北统万城和内蒙古部分古遗址和山海关长城、慕田峪、遵义海龙屯等的遥感考古工作; 2006 年，由科技部支撑计划支持的“ 空间信息技术在大遗址保护中的应用研究 ”项目对京杭运河开展了运河现状与历史演变的综合性研究。

1993 年国家教委批准在华东师范大学成立了“ 城市与环境考古遥感开放研究实验室 ”，刘树人(1998)曾先后在长江下游、丝绸之路、金长城、中原大地等地进行遥感考古研究，取得了显著成效。河南省科学院地理研究所利用遥感技术与考古部门相结合，在考古遗址航空摄影测量、航空影像古文化遗迹解释等方面进行了应用和实验研究。中国社会科学院考古研究所利用航空影像、卫星影像以及浅层地球物理方法(探地雷达等)寻找考古遗迹以及对考古遗迹进行高分辨率无损探测等，为考古发掘和研究提供可靠依据，开展了“ 高分辨率地球物理及卫星遥感在考古资源评估中的集成研究 ”和“ 安阳洹北商城的遥感考古与地球物理勘探 ”等工作。国土资源部航空物探遥感中心对宁夏全境的古长城及北京长城做了航空摄影测量及分析工作。安徽师范大学和安徽省地质遥感中心对隋唐大运河进行了遥感考古研究。中国科学院遥感应用研究所用航天飞机成像雷达数据探测到位于陕西和宁夏交界处干沙掩埋的古长城，并用高分辨率相机对北京老山汉墓成像，圈定出古墓的“ 异常区 ”。

鉴于国内对遥感考古的需求，于 2001 年 11 月在北京成立了“ 中国科学院、教育部、国家文物局遥感考古联合实验室 ”，并在浙江、河南、安徽、陕西、江苏、内蒙古、云南正式成立了该实验室的遥感考古工作站。这种跨部门、跨行业的遥感考古联合实验室以国家需求为目标，通过与地方考古界及遥感机构网络式的广泛合作，旨在推动中国遥感考古事业的发展。2002 年 12 月在北京召开了由遥感考古联合实验室主办的“ 全国第一届遥感考古会议 ”；2003 年召开了“ 人类文化遗产的空间认识 ”香山科学会议; 2004 年举办北京国际遥感考古会议。2005 年 4 月 14 日，在联合国科教文总部中国与联合国教科文组织签署了一份协议，内容是：中国将加入开放式行动，该行动旨在使用空间技术协助世界文化遗产的保护。中国科学院、教育部、国家文物局遥感考古联合实验室与阿根廷空间局、加拿大空间局、黎巴嫩遥感中心、摩洛哥皇家遥感中心和美国宇航局一起，协助联合国科教文组织用卫星监测世界遗产。

# 3 遥感技术在大型遗址探测中的优势与作用

## 3.1 遥感技术在大遗址探测中的优势

在遗址的探测中，与传统田野考古相比，遥感考古在许多方面能获得从地面观测无法得到的大量信息，主要表现在以下几个方面(尹宁 & 王长林, 2003; 赵生才, 2004):

### 3.1.1 覆盖范围广

遥感可以获得研究区的全局信息，特别象中国的长城、大运河、丝绸之路等大型遗址，地面观测只能获得视线内的地物景观，无法构成对全局的图像。遥感图像的成像尺度变化范围大，从中等分辨率成像光谱仪及低分辨率扫描模式合成孔径雷达获得的小比例尺区域图像用于环境考古研究，到Quickbird及IKONOS高分辨率遥感图像用于古遗址的详细研究。

### 3.1.2 光谱范围大

人的肉眼只能观测到可见光部分的电磁波反射能量，而遥感(包括地球物理勘探技术)则能覆盖从紫外线、可见光、红外线、热红外、微波等能量波范围全波段电磁波来探测地物。

### 3.1.3 时空分辨率高

田野考古只能在特定的时间对考古对象进行野外勘查，而遥感考古则可利用卫星高重访频率所获得的数据积累获得研究区的遥感数据，研究考古遗址区随时间变化的地形景观及古遗址的情况。在空间分辨率上，高分辨率商业卫星已经能提供和航空摄影测量所得图像相比的多波段遥感图像。

### 3.1.4 光谱分辨率高

多光谱遥感图像能提供对同一研究区不同谱段的遥感信息，高光谱成像仪能够在一个特定光谱范围内细分出数十至数百个波段，增强了对地物(如考古研究区作物的变化)的识别能力。

### 3.1.5 穿透能力强

合成孔径成像雷达的穿透性可用于干旱沙漠区古地理环境研究，而探地雷达技术则能获取地表下一定深度的考古信息。

### 3.1.6 对考古文物的无损探测

遥感考古具有对地下考古对象无损探测的优点，使用物探方法能探测和研究遗迹的平面形态特征和布局结构，无需进行大面积的揭露，既能节省大量人力、物力和时间，又不会对遗存有任何破坏。

## 3.2 遥感技术在大遗址探测中的作用

### 3.2.1 利用遥感技术对遗址的重大发现

由于保存于地表或地表以下的古代遗迹随着岁月的流逝逐渐荒废，有的变为农田，有的形成村镇，但由于这些遗迹全部为人工建成，与周围没有经过人工扰动的土壤环境存在着差异，这就形成了这一地区在土壤、水分、地表温度等一系列的特别征象，人们在平地观察这些特别征象是微乎其微，而这些差异则造成了遥感图像上的光谱差异，因此这些古遗址能被识别出来；此外，由于雷达的全天时、全天候的成像能力及对一定地物的穿透能力，地物的后向散射特性决定了古遗址能从雷达图像上识别出来。目前已有很多利用遥感技术发现古遗址的实例，说明了遥感在考古应用中的作用。例如：美国的考古学家们利用卫星遥感影像发现了早已沉没海底数千年的古埃及名城亚历山大；欧洲的考古学家根据早期照片发现了多处古罗马的建筑遗址和著名的“罗马大道”；美国宇航局埃姆斯研究中心的科学家利用遥感技术揭开玛雅文明荣枯盛衰的奥秘，成功地识别出了古玛雅遗址的特点；希腊考古学家用红外像片在科林斯湾发现了公元前 373 年毁于地震的古城“Helike”；美国宇航局考古学家从彩红外航空像片上识别出哥斯达黎加森林中的古路径；1994 年航天飞机成像雷达 SIR-C/X-SAR 和 AIRSAR 对处于茂密森林的柬埔寨吴哥古城的研究，重建了吴哥古城的分布范围，使其由原来的 200—400km$^2$ 扩大到 1000km$^2$，重新勾绘出古运河水系，重现已消亡的吴哥古城的壮观原貌。

### 3.2.2 遥感技术在大型遗址的调查、保护与监测中的优势

中国的文物古迹遍及各地，世界遗产 38 处，有大量需要保护和探明的古遗址，其中包括大型古代聚落、古城、皇陵、运河、长城、丝绸之路等，还有许多现在已被列入或今后可能被列入世界遗产的地方。中国有 1200 多个国家级重点文物保护单位，99 个国家历史名城。遥感技术无疑是探寻古遗址、动态监测历史文化遗址的变化情况及古遗址保护的有效手段。以长城为例，中国整个长城从丹东虎山到嘉峪关全长 7000km 以上，由于沿线生态环境的不断恶化，加上人为因素的破坏，破损现象非常严重，特别是在西部干旱荒漠区，多数地段已被流沙掩埋。目前长城只有不到 1/3 修复和保护完好，另有 1/3 残破不全，还有 1/3 早就不复存在。利用遥感技术探明长城的分布，更好地保护好长城。丝绸之路是连接中国与西方文化交流的主要路径，在这条道

路上遗留着许多文物古遗址, 如尼雅古城、楼兰古城、中亚土库曼斯坦的 Merv 古城。丝绸之路遥感考古是 1994 年航天飞机成像雷达过境中国尼雅古城时的一个重要课题, 加拿大等国的研究人员在位于沙漠中过去的绿洲古城 Merv 进行了多学科的遥感考古研究, 利用 GPS 技术和 IKONOS 等图像对古城进行了精确定位和古遗址分析。此外, 近年来中国科学工作者对秦始皇陵、三星堆、大运河的遥感考古研究使我们对文化遗址有更深刻的认识。

**3.2.3** 空间信息用于古环境研究

古代环境的恢复, 对于研究当时的社会、文化、经济、自然地理条件等方面都有着重要的作用。而古地理环境的变迁, 对于古代环境、政治演变的研究也十分重要。利用遥感研究长周期的环境历史变迁, 主要是依据它在遥感图像上所遗留的“痕迹”进行识别。这些特征反映在遥感图像上, 通过色调、阴影、形态、大小、纹理等的差异识别出来(刘建国 & 王清山, 2006; 万余庆 & 周日平, 2007)。

目前, 应用遥感技术进行环境考古, 热点集中在运用多时相、多源和多分辨率航空及航天图像进行考古遗址环境监测、景观考古、环境变化和社会变革的关系研究以及历史时期环境恢复等方面。

哥伦比亚号航天飞机携带 SIR-A 雷达于 1981 年 11 月在东撒哈拉沙漠进行飞行, McCauley 等通过对 SIR-A 图像上沙层覆盖下基岩雷达回波的研究, 揭示出数米沙层下的古河道, 后期研究表明: 非洲北部存在过比现今尼罗河水系更为庞大的河流水系, 否定了那里不存在主干水系的论断。古河道为旧石器时代的人类提供了沙漠中的绿洲, 揭示出当时撒哈拉沙漠的环境条件; 中国科学院遥感应用研究所的科研人员在新疆用多源卫星遥感数据结合数次野外实地验证, 发现图像上的沙带路径由西南流向东北注入到雅马雷克沙漠之下, 揭示了该地区古水系的存在; 利用 20 世纪 50 年代老航片在山东济宁南旺发现了已消失的京杭运河分水岭水柜, 为这一遗址工程的保护规划提供了依据。

**3.2.4** 对地下遗址的无损探测

目前采用的无损探测方法主要包括磁力探测法、电阻率探测法、微波脉冲“探地雷达”以及地震探测法等。

中国在这方面的起步比较晚, 主要成果有华东师范大学用探地雷达对浙江绍兴“印山大墓”进行的无损探测; 采用航空遥感高光谱技术和热红外遥感技术与磁法、电法等 20 多项高精度的物理探测技术, 对秦始皇陵区 2.13km$^2$, 陵园区 56.25km$^2$ 进行遥感和地球物理综合考古研究(谭克龙等, 2005)。国际上, 以色列的专家利用热红外传感器在 1333m 的高空成功对戈兰高地的埋藏于土层下面的考古遗址进行了探测, 并进行了热红外制图, 开创了热红外遥感考古的先河。

**3.2.5** 考古专题制图和文物考古信息系统

遥感考古研究的主要工具是遥感图像, 图像本身具有可以长期保存的特性, 因此可以从早期保存的遥感图像上发现已被破坏的古迹, 从现在的图像发现现有的古迹, 制成考古信息专题图, 在图像上保存这些古迹的位置、范围以及古迹的真实外貌特征。

经过纠正的遥感图像有很高的精度, 可以从图像上对遗址的范围及形状进行直接测量, 并将结果直接转绘到地图上, 具有很高的参考价值。

目前, 在国际上, 利用遥感进行考古制图是考古的主要内容, 发展十分广泛, 尤其是高分辨率卫星图像和航空照片, 是大比例尺制图的主要数据源。利用遥感和 GIS 技术进行大规模的遗址调查, 精确定位, 以供进行环境监测、遗址定位以及预测之用。

GIS 在考古学中的应用研究是多方面的, 可以应用于从考古数据采集到数据存储、分析、解释以及表达的各个方面。具体总结为建立考古信息管理系统, 建立考古遗址预测模型, 进行考古遗址的发展和扩张, 景观考古 GIS 研究等。

**3.2.6** 空间技术与古人类遗址和环境重建

自 20 世纪 90 年代, 出现了虚拟遗产(或虚拟考古)技术, 它是指运用先进的计算机技术进行世界历史、文化、自然遗产的保护与发展的研究。虚拟现实技术是其应用发展过程中的关键技术。选择将虚拟现实技术作为虚拟遗产研究的技术层次支撑, 是因为虚拟遗产的研究所要表达的信息是多维的, 既要有历史真实性, 又要有文化艺术性, 还要求有环境的现实性。这些多维度信息的表达就目前的计算机技术, 需要虚拟现实技术的高性能硬件设备的支撑。在虚拟遗产研究中, 还涉及其他各类计算机技术, 例如扫描技术、信息处理、计算机辅助设计、地理信息系统等, 具体应用哪些技术需根据不同的研究项目而定。从总的概念, 虚拟遗产强调的是要表达出历史的文化现实, 反映人类在发展过程中对科学与艺术创造性的努力和不断提升的知识、信仰和价值的体验。虚拟遗产是目前国外历史遗产保护和发展的新方向和趋势, 越来越多的人正从事于这方面的研究。中国是历史文明古国, 其丰富的历史文化遗产已成为世界历史文化遗产的重要组成部

分。进行虚拟遗产研究既推动中国历史遗产保护与发展，又与世界的发展潮流相适应，同时对于提高中国的历史文化遗产在世界历史文化遗产中的地位具有极大的意义。

利用虚拟遗产技术可以重建历史文化遗址。大英博物馆内演示的古希腊神殿，美国洛杉矶美术馆演示的古罗马城堡，都是根据残缺部件“修复”仿真的。敦煌石窟、“数字故宫”也即付诸实现。美国学者对新墨西哥州的印第安土著人居住场所进行了虚拟恢复，埃及学者把大金字塔进行了不同角度的虚拟仿真。日本学者用虚拟现实技术结合空间信息数据模拟中国湖南稻作文化时期距今 7000 年的彭头山遗址，再现了当时的城市布局景象。我们利用虚拟遗产技术恢复已消失的古城(如楼兰古城，大运河古河道)的原貌，同时也对现今古迹进行虚拟现实仿真，为文物保护部门提供宝贵的电子资料。

## 4 遥感考古研究实例

近年来，随着中国经济实力的增长和遥感技术应用水平的提高、应用领域的拓宽和国家对遥感考古的重视，中国遥感考古技术应用水平不断提高，遥感技术在考古部门得到越来越多的应用，取得了大量研究成果。以下是遥感考古联合实验室近年来取得的部分成果及实例。

### 4.1 遥感考古

#### 4.1.1 京杭运河

京杭运河作为古代中国人创造的伟大工程，是华夏民族给世界留下的宝贵的文化遗产。近年来，在文物部门、有关专家和有识之士的努力下已制定了京杭运河的申遗计划。由于运河的本底跨度大及运河文化遗产的多样性，首先是应用遥感技术对 1794km 长的运河河道、周边环境进行现状和历史演变研究，以便为制定保护规划方案提供科学依据。

应用不同时相、不同分辨率的遥感图像对运河进行对比分析，可以得出 60 年来运河及运河城市的环境变化情况。图 1 是京杭运河流经地域与 SPOT5 数据获取情况，图 2、图 3 和图 4 展示了运河沿线 3 个地区的航片与遥感影像的对比效果。

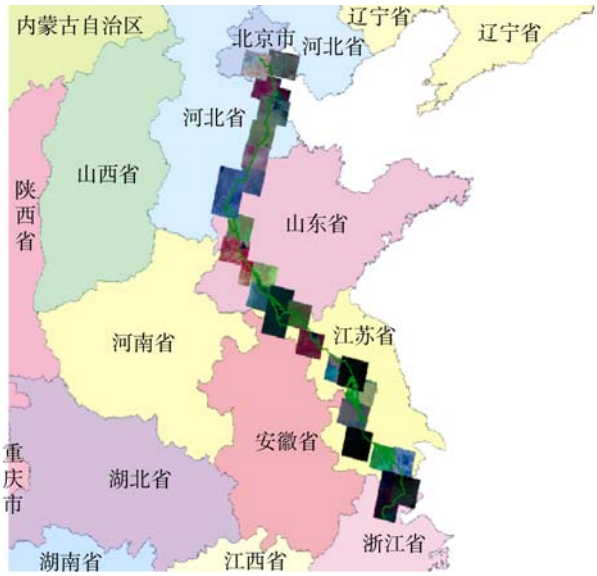



图 1 京杭大运河沿线 SPOT5 影像全图

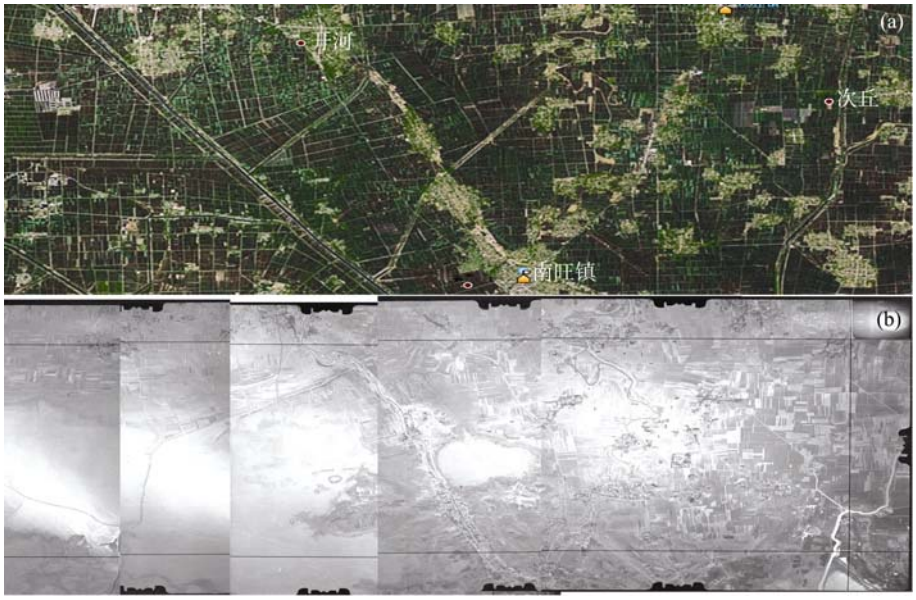
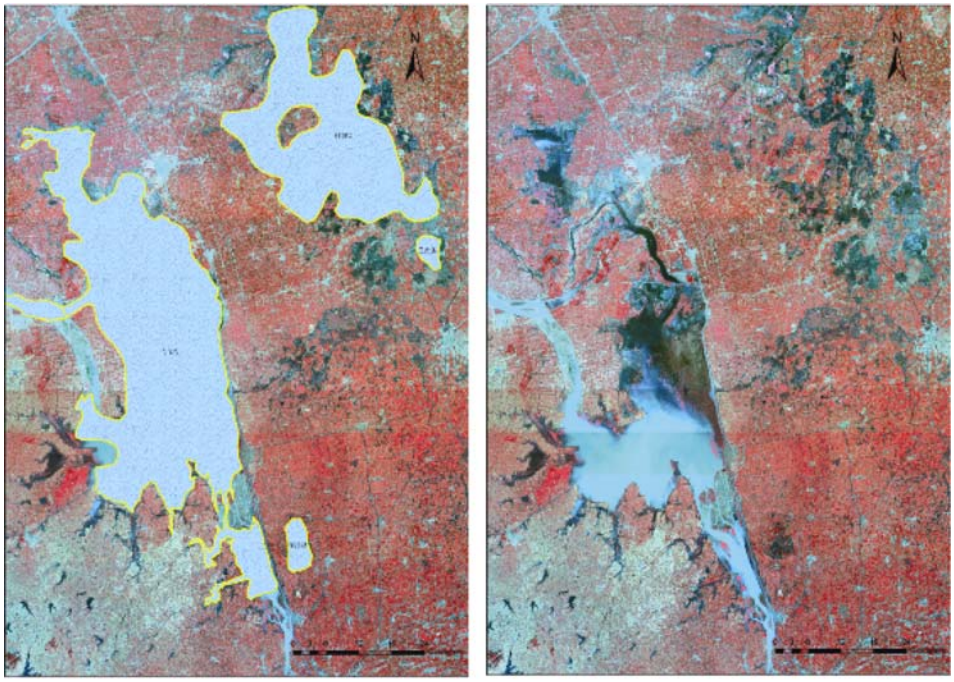



图 2 山东济宁南旺为京–杭运河分水岭工程所在地

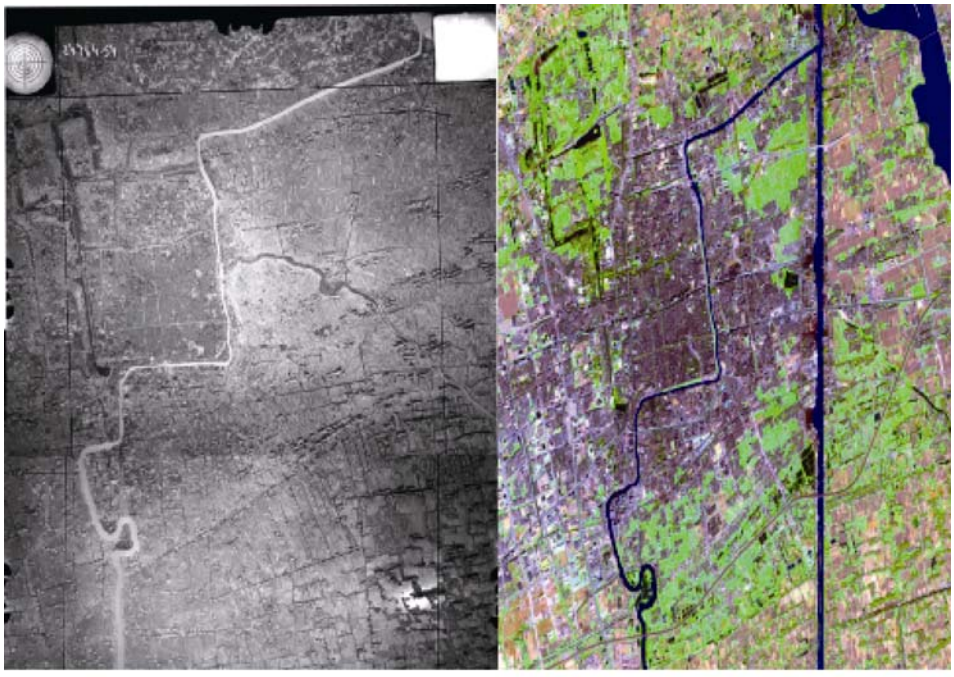
(a) 2005 年遥感影像，水柜已消失，变为农田; (b) 1954 年航片，运河两旁水柜水体依然存在



(a) (b)

图 3 高邮湖、射阳湖不同历史时期运河沿线湖泊的变化

(a)100 年前; (b)2005 年



(a) (b)

图 4 近 60 年运河及运河城市变化信息

(a)20 世纪 50 年代扬州; (b)现代扬州, 城市面积扩展了 60 倍

**4.1.2** 长城

中国的长城是人类文明史上最伟大的建筑工程, 它始建于 2000 多年前的春秋战国时期, 秦朝统一中国后联成万里长城。汉、明两代又曾大规模修筑。

长期以来人们就想摸清长城的具体长度、位置和空间展布情况。但由于长城分布的跨度大, 地形地貌复杂, 加之有的地段已被埋没, 难以得出统一的结论。国家文物局拟应用遥感技术对长城进行一次全面的普查。在此之前, 中国科技工作者也利用

遥感手段对长城的探测与发现进行了尝试，其中代表性的工作有郭华东等(1997)利用多波段全极化成像雷达 SIR-C 识别出位于宁夏、陕西交界处的明隋两代被干沙掩埋的古长城(图 5)，以及应用 Quickbird 高分辨率遥感影像及其他影像对山海关长城老龙头的识别与环境变迁分析(图 6)。

**4.1.3** 内蒙古古城遗址

内蒙古文化遗址丰富，但由于内蒙古面积广大，许多遗址分布在沙漠、草原深部和无人区。要用地面调查的方法对这些遗址进行调查很难达到普查效果。2002 年，使用北京科源轻型飞机实业有限公司制造的蓝鹰 AD-200 轻型飞机，对内蒙古自治区中部及陕北的古城址、遗址进行了航空摄影考古勘察，取得了良好的效果。该飞机结构简单，体积小，质量轻，可以方便快速的拆装，用普通卡车即可运输。同时对飞机起飞、降落的场地要求低，平坦的草地、公路等均可，要求跑道也比较短，给普查工作带来极大方便。图 7(a)是 AD-200 轻型飞机，图 7(b)、图 7(c)是 2002 年用航空数码相机拍摄到得内蒙古居延遗址群。2005 年 AD-200 轻型飞机在内蒙古境内航拍调查时发现长城、秦直道及未定名古城等新遗址(图 8)及玉宁卫故城遗址(图 9)。

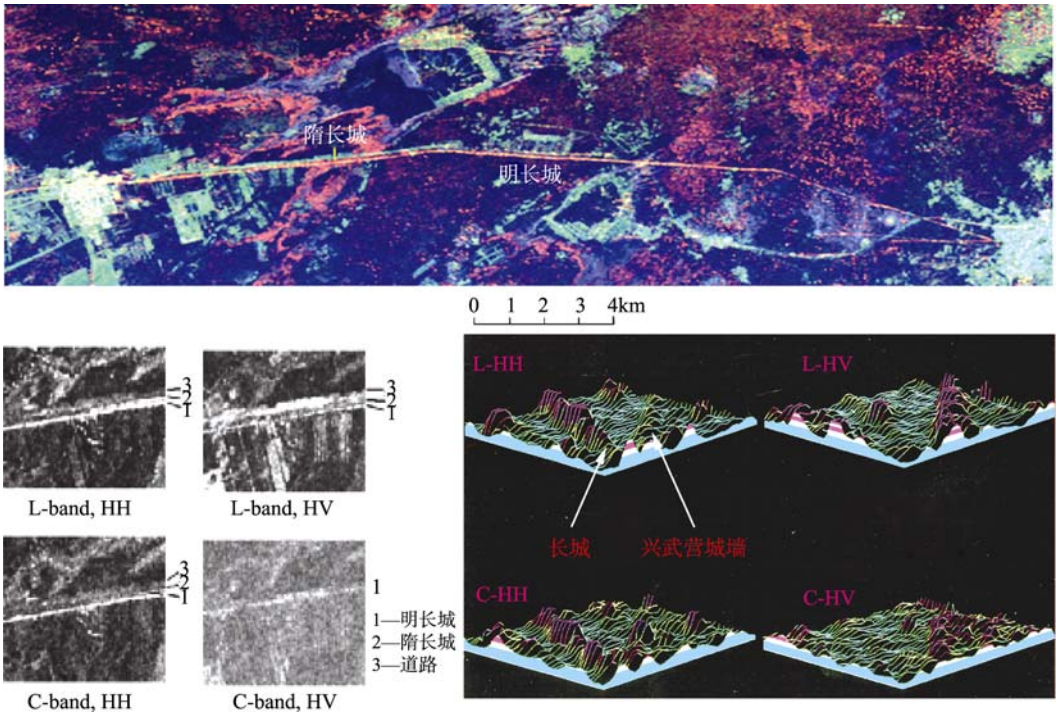



图 5 用多波段多极化 SIR-C 雷达探测到陕西定边与宁夏盐池一带明、隋两代被干沙掩埋的长城及不同极化组合下的探测效果

图 6 山海关长城老龙头 Quickbird 图像


图 7　AD-200 轻型飞机及航空数码相机拍摄的内蒙古居延遗址群

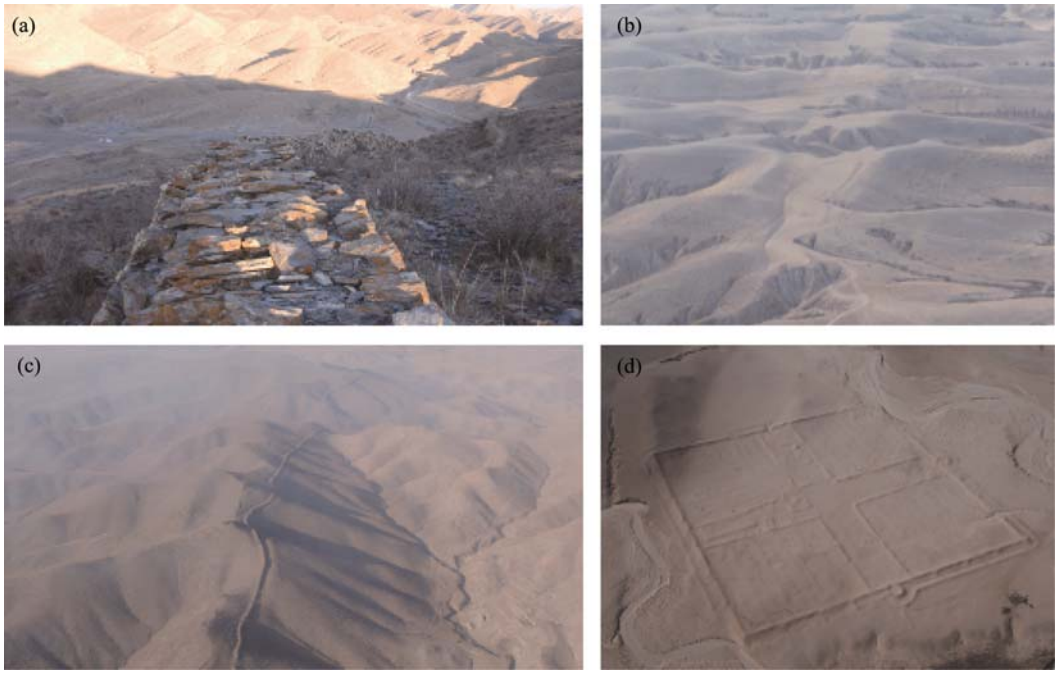



图 8　2005 年 AD-200 轻型飞机在内蒙古境内发现的新遗址

(a)、(c)为长城; (b)秦直道; (d)未定名古城

图 9　内蒙古玉宁卫故城

### 4.2　虚拟现实

通过空间信息技术与 VR 技术结合，实现对大型古遗址的空间地理信息以及各种环境、人文信息的可视化表达、网络化与集成化管理，给人更加自然、方便、快捷的使用空间信息的工具；构筑一个三维动态、实时交互查询、可进行多种分析和管理调度的“大遗址虚拟现实系统”平台，汇集文化遗产管理和考古发掘的信息，进一步拓展考古学和文化遗产管理研究的领域。为考古文化信息资源共享和

有序利用，做到可持续发展。

大遗址保护虚拟现实系统建设技术方面开始了如下工作:

(1)针对大遗址的虚拟现实技术，已经完成了大遗址的三维空间信息获取方法与数据结构等方面的研究工作，实现了大规模数字地形的三维可视化流程，研究了大遗址演变过程仿真(simulation)方法，开展了动态水体生成方面的研究。

(2)三维仿真场景开发: 开发了北京通州、山东南旺、古城扬州等虚拟现实场景(图 10、图 11)，实现了单机版的多层次场景的融合与管理。开发了网络三维场景的 Active X 控件，实现了小场景的三维网络浏览。

(3)开发了基于 Microsoft DNA 的 Server/Client 的系统，开发的三维浏览服务器/客户端程序，正在进入测试阶段。

(4) 数据处理方面进行了遥感数据 ETM、SPOT5 数据的融合与分层分块处理，处理了 1∶25 万、1∶5 万 DEM 模型，研究建立中国东部地区涉及运河的全境遥感影像结合的虚拟现实可视化系统。

## 5 遥感技术在大型遗址保护面临的一些问题

遥感技术以其独特的优势在探测和保护大型遗址中发挥着越来越重要的作用。但与其他应用领域相比，还存在一定的差距:

(1) 遥感考古是自然科学与社会科学相互渗透的科学，要求科学工作者必须具备遥感技术知识和

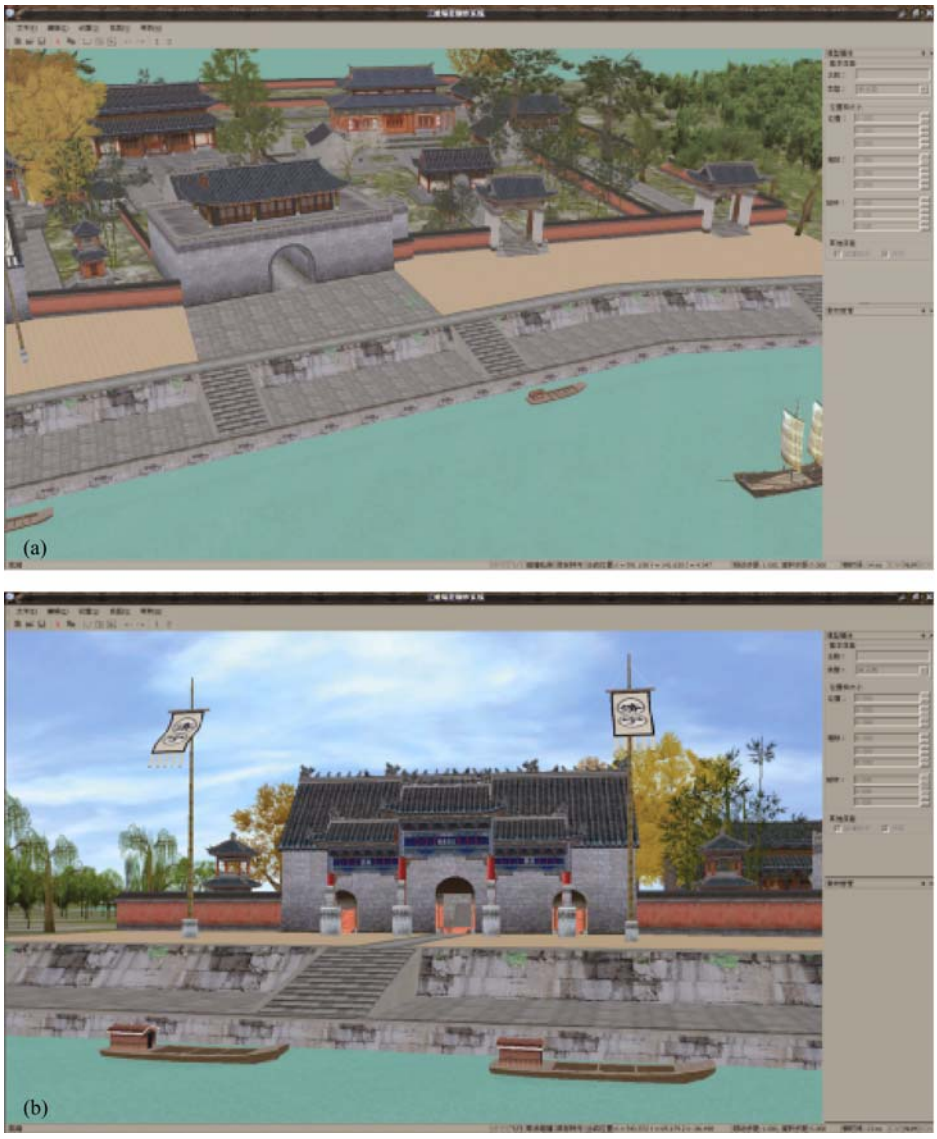



图 10 山东南旺京杭运河水利枢纽复原效果

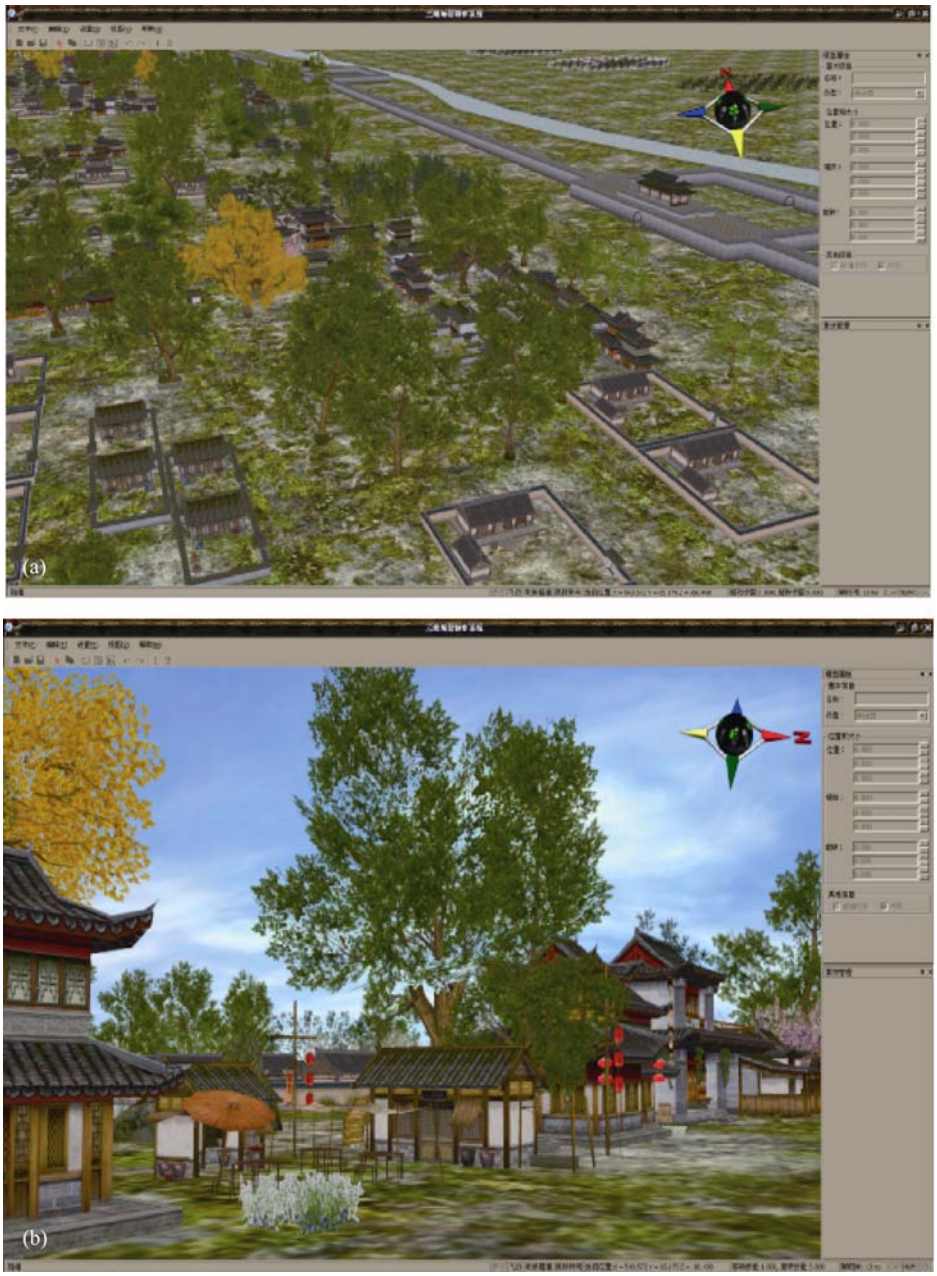



图 11 以唐代古城为蓝本，恢复建立扬州古城运河各段风貌以及周边古建

历史考古知识;

(2) 由于遗址存在的自然环境的复杂性和多样性，特别在人类活动强烈区，干扰因素大，给遗址的遥感信息提取带来一定困难;

(3) 不同时代、不同地区、同一时代、同一地区的遗址，从结构到物质组成多不相同，而电磁波与其相互作用的机理尚未做过系统的理论研究;

(4) 大型古遗址存在的状况大多属半掩埋或掩埋，如何从复杂的地物中提取这些弱信息，是目前要解决的关键技术;

(5) 遥感考古是一门跨领域、跨学科的科学范畴。在进行遗址研究，需结合考古学、环境学、物探、钻探等手段和方法进行综合研究。

遥感技术在遗址的研究中已展现了其巨大的应用潜力。随着遥感技术的不断发展和完善及遥感考古研究的不断深入，与其他应用领域一样，遥感在考古工作中的应用会得到不断的完善和提高，并将为中华文明探源与重要遗址的保护做出贡献。

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