A NEW ARCHAEOLOGICAL REMOTE SENSING TECHNOLOGY

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ABSTRACT:

Contrast to traditional archaeological technologies, remote sensing technology can help do exploration and make maps for large-scale underground relics rapidly and cheaply. But according to numerous former remote sensing archaeological practices, remote sensing technology was well effective only when a certain amount of ground remnants existed in the target archaeological sites, while where there were not ground remnants, remote sensing analysis would obtain no useful results. What archaeologists expect most is an effective archaeological remote sensing technology for archaeological sites without any ground remnants existing. Taking Shenhe loess tableland and the Mausoleum of Emperor Qinshihuang (MEQ) (259–210 BC) as case studies, this paper introduces a new archaeological remote sensing technology-- hyperspectral remote sensing for archaeology. It achieves underground relics exploration successfully in no ground remnants conditions by detecting and identifying weak spectral anomalies.

1. INTRODUCTION

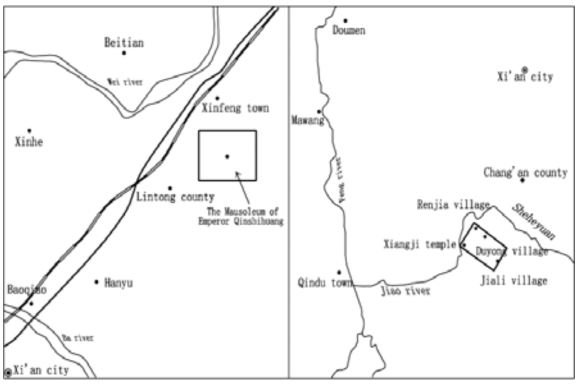
1.1 Brief Introduction of Remote Sensing Archaeology

Remote sensing archaeology is to explore cultural relics from space borne images and ground survey (Kvamme 2005). Overlying soil on the relics is distinct from surrounding soils in color, texture, humidity, and compactness, especially, when the farming soil layer has been ploughed (Chen 2004, Tan et al. 2005). Soil differences in looseness, fertility, water content caused by underground relics usually lead to anomalies in growth and distribution of vegetation (Scollar et al. 1990) or differences in height, density and color of crops and weeds. In addition, relics usually appear with special micro-relieves and in special geometrical shapes, especially large-scale ground and underground projects such as excavations and fillings of mausoleum pits and accompanying buried pits, soil taking from ground and soil heaps on mausoleum, dug ditches that lead to changes of ground shapes and form certain patterns (Tan et al. 2006). These differences will affect the absorption and reflection of solar radiance and thermal radiation from objects (Dabas and Tabbagh 2000). Weak changes of thermal emission and spectral characteristics of objects will be the indications for remote sensing archaeology. Remote sensing technology can perceive the spectral characteristics of objects on ground and from a short distance beneath the surface (1-2m) (Kvamme 2005).

Usually in the relics distributed areas, there are no obvious differences in soil, vegetation and physiognomy because of human activities and cultivations that have been lasting for hundreds or even thousands of years, therefore it is difficult to interpret distinct anomalies in ordinary images. Previous remote sensing archaeologies were only effective for the sites where ground remnants existed. If there were no ground remnants, remote sensing didn't have great advantages actually (Liu 2006). What archaeologists expect most is a new effective archaeological remote sensing technology for archaeological sites without any ground traces existing. So the latter is of more practical significance in remote sensing archaeology.

From 2003 to 2006, funded by a key project of National High Technology Research and Development Program of China (863 Program) and National Historical Museum of China, the authors carried out application research on hyperspectral remote sensing archaeology about the Mausoleum of the Emperor Qinshihuang (MEQ) (259–210 BC) and Shenhe loess tableland in Chang'an county (20km south of Xi'an city), Shaanxi province. Important discoveries were acquired.

1.1.1 1.2 Introduction of Research Areas



Research area

Figure 1. Relative locations of research

Located at the middle of Weihe River plain and the north foot of Li Mountain, the Mausoleum of Emperor Qinshihuang is 30 km away from Xi'an to the east (see Figure 1). According to historical records, when MEQ had been built up, there were towering pyramid-shaped mound, continuous tamped soil city wall, majesty palaces and temples. There were also underground palace built through three water-bearing beds, many accompanying buried pits with luxury properties, and plenty of buried articles and jewellery. But the ground buildings had been burned down and destroyed due to the dynasty change at the end of Qin dynasty, leaving only the solitary pyramid-shaped mound.

Along the banks of Feng River near Xi'an, Shaanxi province, the early ancient capitals Feng and Hao of Westzhou Dynasty were sited according to historical records. Taking the ancient capitals as centers, there are abundant ancient cultural relics distributed from Huxian county in the west to Weiqu of Chang'an county in the east and from Qinlin mountain in the south to Xianyang loess tableland in the north (Zhu 1998). This area belongs to alluvial and diluvial plains of Wei River and Feng River, and Quaternary strata are well distributed, of which the thickness is about 800 meters. Along Feng River banks, even though long archaeological investigations have been carried out with traditional archaeological methods since 1931, little information has been acquired about this area because of geological and geo-morphological restrictions and longtime human reclamation and cultivation activities.

According to researches of archeologists from National Historical Museum of China and Archeological Institute of Shaanxi Province, loess tablelands of Shenhe tableland and Xiliu tableland are located at the highest height in the area, with the altitude of about 440～580m, and the depth of groundwater table is about 20～50m, which were suitable for tomb construction by ancestors. Therefore, the research took the surrounding area of Renjiazhai village and Xiangji temple village and Jiali Village in Shenhe loess tableland as an experimental area. See figure 1.

2. RESEARCH METHODS AND RESULTS

The relationships between surface spectral reflectance and ground temperature, soil moisture and ingredients of soil are firstly determined by field measurements. And secondly the links of vegetation growth, soil ingredients, and soil structure changes to the characteristics of hyperspectral image are summarized. Simultaneous field measurements of ground spectrum, thermal infrared temperature, and soil moisture are required to determine the thermal radiation and temperature characteristics of nighttime and daytime hyperspectral images. Thirdly, endeavoring to analyze and interpret temperature, soil moisture and ingredients anomalies from hyperspectral images in the research areas combined with historical and cultural relics knowledges is key research work, because we can possibly get lots of anomaly areas worth doing further research. Finally, field boring exploration and historical analysis that eliminate false anomalies can verify the anomaly areas.

1.2 Data Acquisition

OMISII spectrometer developed by Shanghai Institute of Technical Physics, Chinese Academy of Sciences was applied for hyperspectral scanning. There are 68 bands from visible, near infrared, short wave infrared to thermal infrared in OMISII. Daytime and nighttime scannings were carried out in each research area, and the ground resolution was 3.6m. Simultaneous field measurements of ground spectrum, thermal infrared temperature, and soil moisture were also done in the scanning area with the flight. Thermal Infrared meter, soil moisture meter and Field Spectral meter provided the parameters for calibrations of image and relevant quantitative analyses.

1.3 Image Processing and Results

General image processing methods, such as color composition, grey stretching & transforming, are still powerful some times in extracting information, but for hyperspectral images with much more bands, the following methods are used to utilize all bands sufficiently to find information of cultural relics.

2.1.1 2.2.1 Visible and Short Wave Infrared Image Processing

1) Spectral Angle Mapping－SAM

In N dimensional space (N bands), pixel classification is decided by similarity of image pixel spectrum and the reference. Regarding the spectral responses of N bands as N dimensional space vectors, the spectral angle from a pixel to the endmember represents the matching level, smaller angle means more similar. See Figure 2, and the calculation formula is (1).

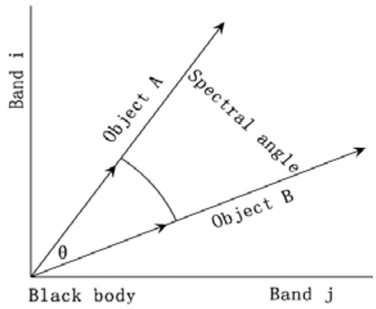


Figure2 Spectral angle

$$\theta = \cos^{-1}\left(\frac{\vec{t}\cdot\vec{r}}{\|\vec{t}\|\cdot\|\vec{r}\|}\right) = \cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i r_i}{\left(\sum_{i=1}^{nb} t_i^2\right)^{1/2}\left(\sum_{i=1}^{nb} r_i^2\right)^{1/2}}\right) \quad (1)$$

where θ = spectral angle

nb = total bands used in SAM

t = spectrum of unknown objects (to be classified)

r = reference spectrum (known object)

i = number of bands used

2) Linear Spectral Unmixing

Usually, there is not a sole object in one pixel of remote sensing image because spatial sampling interval is larger than ground objects during remote sensing scanning. Linear spectral unmixing is used to estimate the percentage of components in one pixel.

3) Matched Filter

Based on user-defined endmembers, each pixel is separated partly. Matched filter is used to calculate the percentage of user-defined endmembers of pixel by partial unmixing. The percentage distributed map of each endmember is determined by matching spectral curve of pixel in imagery and that of ground object in known spectral library. This method doesn't need all endmembers in image.

4) Spectral Feature Fitting－SFF

Based on characteristics of spectrum absorption, non-classified ground object spectrum could be matched for classification with referenced spectrum by using the least squares method.

5) Pseudo Colour Composition and Enhancement

Cultural relics are distinct in some bands of hyperspectral imagery because soil ingredients, moisture and the growth differences of vegetation related to historical relics cause absorption and reflectance anomalies. For example, the pseudo color composition image of band 62, band 63 and band 64 clearly show the westward mausoleum passage and the underground palace of MEQ. See Figure 3.

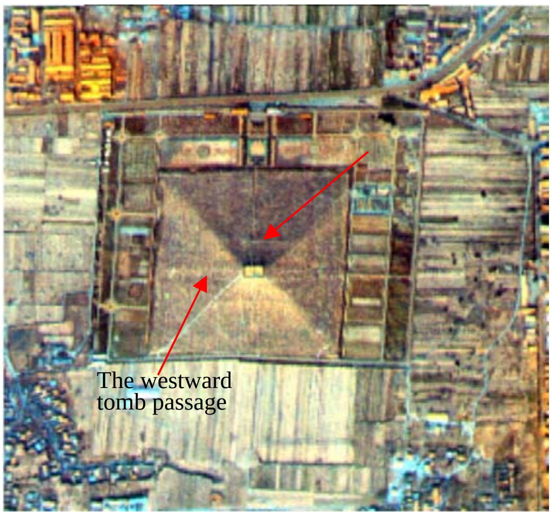


Figure 3 The westward tomb passage and the underground palace

2.1.2 2.2.2 Thermal Infrared Image Processing

According to the simultaneous temperatures and spectra measurements of ground surface and the pixel values on thermal infrared bands of the same points in OMIS images, temperature retrieval model is set up by regression analyses.
Formula 2 gives an example model in Shenhe tableland area.

$$T=-2.446+0.0152*DN \quad (2)$$

where T = retrieval radiant temperature value of ground surface
DN = pixel value in thermal band image

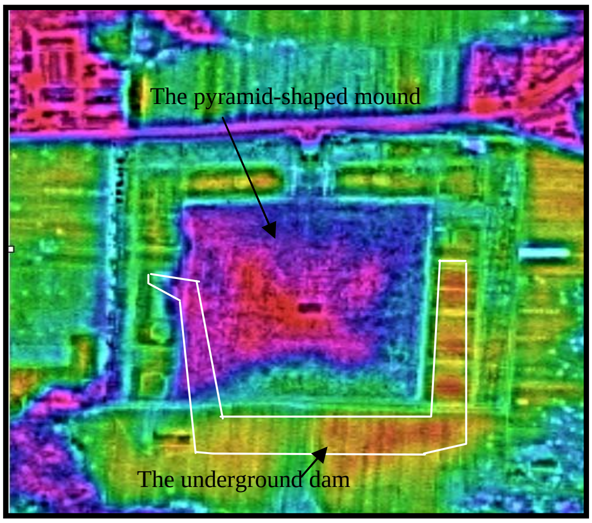


Figure 4 Pseudo color composition of night time thermal infrared image

The coefficient between the calculated value and measured temperature is 0.946; the mean error is 0.378°C. Radiant temperature image can be acquired after calculation of the whole thermal band.

In order to enlarge the differences of ground information and identify anomalies easily, enhancement of image is carried out. Figure 4 is a pseudo color composition image of thermal infrared bands of the pyramid-shaped mound of MEQ, which shows the moisture changes caused by the Underground Dam, and the thermal anomalies of the Pyramid-shaped Mound, and also shows the underground temperature differences and indicates the location of the Underground Palace under the Pyramid-shaped Mound.

3. EXPLORATION VERIFICATION

In November 2004, Archeological Institute of Shaanxi Province and Geological Investigation Bureau of China applied shovel drilling and geophysical exploration that confirmed the location of the Westward Tomb Passage, the Underground Dam and the Underground Palace of MEQ were in accordance with the remote sensing interpretation results. After two months' hard working, what we had interpreted were proved right by the results of both drilling and geophysical exploration.
In spring of 2006, Archeological Institute of Shaanxi Province selected 8 anomaly areas to confirm the remote sensing interpretation results by shovel drilling in Shenhe tableland. They found that 7 of them had ancient tombs and relics. In these 8 anomaly areas about 46 ancient tombs, 8 ancient rubbish pits, hundreds of recent and contemporary tombs and about 10 ancient active loess pits were found. Figure 5 and Figure 6 show hyperspectral information extraction and verification of No.1 anomaly area.

Figure 5 Sketch map of No.1 anomaly area

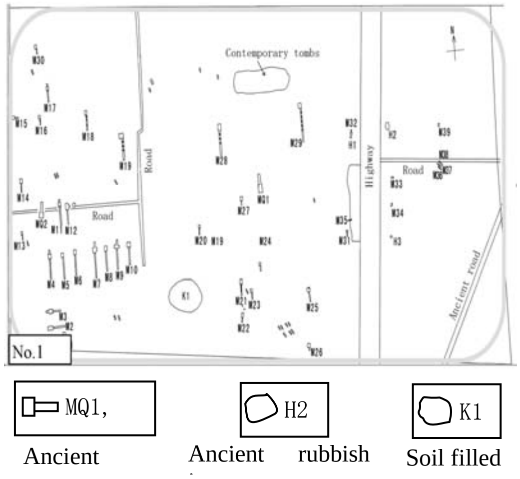


Figure 6 Sketch map of ancient tombs distribution verified by drilling in No.1 anomaly area

4. CONCLUSIONS AND DISCUSSIONS

This research demonstrates that hyperspctral remote sensing is effective for archaeology even when no ground remnants or other traces are found. Hyperspectral remote sensing could detect and identify weak spectrum differences of ground objects, and it deserves to penetrate the archaeological research. The selection of hyperspectral remote sensing time for archaeology is important. And the best season for hyperspectral scanning is when crops have been harvested and the soils have been exposed to insolation for a longer time. Shallow-buried tombs usually lead to less moisture and higher thermal anomalies of the covering soil. Thermal infrared image scanned at nighttime is more effective for temperature anomaly detection than that at daytime.

To the authors' knowledges, if an underground building is large in scale, geometric shape is regular and physical property is distinct, the spectral anomalies will be much clear. Some ash pits filled with rubbish or bones will change the thermal properties and spectrum of overlying objects due to lower density, higher fertility and more diversified humidity. Therefore, the size of detectable cultural relics relies on spatial resolution of image, larger relics or group of small relics densely distributed will be more detectable by hyperspectral remote sensing because they can more possibly cause anomalies in thermal properties and vegetation growths.

The scanning time for hyperspectral image in Shenhe tableland was a little late, and the ground crops had been already 5～10cm high, and the percentage of vegetation coverage reached to 60～70%. The spatial resolution of image was about 3.6 m. The lower resolution had had a disadvantageous influence to the results of studying.

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