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Original article

Improved detection of archaeological features using multi-source data in geographically diverse capital city sites

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ABSTRACT

As one of the world's oldest civilizations, China has a continuous history that extends for more than 5000 years. There are many important capital cities throughout China. However, little information is available in the literature about capital city sites using remote sensing because of its various geographical conditions. This paper designs new methodologies for detecting archaeological features in Northern and Southern China based on multi-source remotely sensed data. Based on various environmental factors, multitemporal images were interpreted to analyse an ancient city located in Southern China, while the integral of the Normalized Difference Vegetation Index (NDVI) time series and thermal infrared images were employed to detect the archaeological features in Northern China; these results were then cross-compared with each other. The results demonstrate that the use of integrated remote sensing technology can provide valuable information and indications of archaeological remains in ancient capital city sites in different geomorphological and vegetated environments in China. Our results also demonstrate that capital city sites can be detected using the proposed approach.

1. Introduction

The increasing development of remote sensing techniques has promoted their application to archaeology. Remote sensing is extremely useful in archaeological prospecting due to its high quality, detailed information and large-scale coverage. Many applications have demonstrated the value of using remote sensing in discovering, investigating and recording archaeological targets [1–3]: the visible, thermal infrared and hyperspectral bands are effective in identifying archaeological features referable to buried remains, such as roads, walls, and channels, including the Great Wall and the Grand Canal [4–8]; very high-resolution multispectral satellite imagery has been used in a series of archaeological studies to identify linear features and to conduct archaeological surveys [9–11]; and previous studies have demonstrated that the thermal infrared band could reveal buried archaeological features, some of which were not evident on the ground or in optical images [12–15].

Since 1929, when the concept of archaeological marks were first proposed and explained [16], it has been accepted that the presence of underground archaeological remains can influence the growth of crops on the ground to create positive or negative crop marks, which make it possible to detect underground archaeological sites using satellite images [17,18]. However, these archaeological features are still difficult to identify from the background due to their similar compositions after being exposed to their natural surroundings for several thousands of years. Moreover, based on their diverse geographical environments and physical characteristics, archaeological marks may appear to be different even in the same images [19]. Although archaeological marks were detected in previous studies in China [20], the application of remote sensing to archaeology is still challenging in practice in China due to its vast geographic area and rich cultural heritage. Capital city sites are located in various physical environments with different climatic features all over China. Therefore, few systematic applications using remote sensing have been proposed for the research of capital city sites. Many studies have attempted to perform

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large-scale spatial detection in regions with homogeneous landscapes and land cover or small sites [21]. For example, Liangzhu and Erlitou are two capital city sites, and little information is available in the literature about performing archaeological research using remote sensing at these two sites. Further studies are still necessary for analysing the non-homogeneous landscape areas where these two capital city sites are located.

Despite the extensive application of remote sensing in archaeological research, there are still some issues limiting the more accurate and effective detection of archaeological targets. Although thermography is regarded a useful complement to archaeological geophysics, most archaeological applications using thermal images have been based on airborne thermal data [15,22–24]. However, few investigations have been carried out to detect archaeological traces using satellite thermal infrared images because their spatial resolution is too low to identify many small archaeological features [15,19]. The VNIR and SWIR bands of ASTER have been proven to be useful in the identification of archaeological remains using spatial autocorrelation [19]. Satellite thermal infrared images can be effective in assessing large archaeological features in archaeological investigations due to their high availability, large coverage and low cost compared to airborne data.

According to Masini and Lasaponara (2017), the proxy indicators of archaeological interest can reveal the differences between an archaeological feature and its immediate environment. Crop marks are commonly employed as proxy indicators to detect and interpret buried archaeological features in vegetated areas [17,25–29]. Vegetation indices (particularly the Normalized Difference Vegetation Index (NDVI), as well as RVI, VIN and SAVI) are frequently applied to detect crop marks [30–33]. However, most recent studies have been based on a single NDVI date without considering temporal information [34]. It has also been suggested that a single NDVI date can only reflect several archaeological features [35].

The more recent studies by Agapiou demonstrated that there were evident differences in the TM/ETM+ NDVI time series between archaeological features and their surroundings in regions where winter wheat is cultivated; however, the three areas in Agapiou et al.'s study did not have the same cultivation method or homogeneous vegetation cover [36]. It is hoped that the integral computation of the NDVI time series during the selected optimum phenological stage can further enhance the evident differences linked to the archaeological features in flat areas with homogeneous crop cover, such as the Luoyang Basin, by reducing the contingency and non-significance resulting from the use of a single NDVI date. As one of the cradles of Chinese civilization, Luoyang used to be the capital city of thirteen dynasties; since 2015 four sites have been included in the World Cultural Heritage list in Henan Province, China [37]. In summary, little work has been devoted to the detection of archaeological features in complicated land cover contexts using the integral of the NDVI time series.

Satellite thermal data are rarely used to detect crop marks in the literature due to their inadequate resolution for archaeological targets. Little research has focused on the long-term integral of NDVI. We also aim to test the reliability of satellite thermal data and the integral of the NDVI time series for detecting archaeological anomalies in flat areas with homogeneous vegetation. These improved methods can be used to obtain reliable results.

In this paper, new methodological frameworks were designed for two geographically diverse capital city sites (Liangzhu and Erlitou) in China using multiple sources of remotely sensed data in order to facilitate the reconnaissance of marks of archaeological interest. To address the issues associated with the use of remote sensing techniques in archaeological studies, improved methods were integrated in these methodological frameworks. Multitemporal image analysis was utilized for the Liangzhu site to identify its archaeological features, and thermal data were processed to detect the archaeological marks in Erlitou. Additionally, the NDVI time series during an entire phenological stage was analysed to determine the optimal phenological stage for archaeological detection; then, the integral computation of the NDVI time series during the best stage was performed. This study provides a reference for the application of remote sensing techniques in ancient capital cities located in various environments in China.

2. Study area and data sets

2.1. Study area

As the most typical representatives of capital city sites, Liangzhu and Erlitou were the largest settlements prior to the Shang Dynasty [38], with areas of approximately 300 ha. Liangzhu is located in Southern China, while Erlitou is located in Northern China; thus, they have different climate, hydrology, soil and vegetation conditions. Therefore, it is worthwhile to explore how different methodological frameworks can be designed to detect archaeological features in capital cities with various archaeological conditions.

The Liangzhu ancient city is located in Hangzhou, Zhejiang Province, which is located in the mountain and plain transition zones. Here, abundant water resources and the warm climate provide good conditions for rice growth. The Tangshan earthen wall and Penggong Dam are two water conservancy facilities that were constructed by the Liangzhu ancients, and some of their sections are unknown to archaeologists. The widths of the city wall and dam make it possible for them to be identified from satellite images.

Erlitou is located in the Luoyang Basin, Henan Province, Northern China. The Luoyang Basin is located in the transitional zone of the second step of the typical ladder topography to the third one. The staple crops grown in the Luoyang Basin are wheat and corn. Some capital city sites have been found in the plain of the Luoyang Basin. The historical importance of Erlitou makes it one of the most important and attractive archaeological sites of ancient China [39]. However, the actual area of the Erlitou sites is likely much greater than has been published. More studies are required to identify additional Erlitou sites.

2.2. Data sets

Archaeological research involves using not only remotely sensed data but also thematic information, such as archaeological reports, local county annals and climatological data, to understand archaeological sites.

2.3. Historical remote sensing data

The landscape in China changed significantly after the 1970s, and especially after the 1990s, due to agricultural cultivation, multiple periods of land levelling, rapid economic development and urban construction [40,41]. Thus, old aerial and satellite imagery are quite important for archaeological research in China because they document the past landscape and preserve subtle archaeological information.

2.4. Historical aerial photographs

Old aerial photographs of the Liangzhu site were taken in the 1970s, while colour infrared photographs were taken in the 1990s. These images are very meaningful for archaeology because the land use in China changed dramatically after the 1990s.