Historical ruins of remote sensing archaeology in arid desertified environment, northwestern China

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Abstract. Silk Road is an important exchange channel for human communication and culture propagation between ancient China and the West during historical periods. A lot of human activities performed in Silk Road and many historical ruins leave behind to present. Archaeological ruins can play a significant role in studying and restoring the past human activities, as well as understanding regional environmental changes. There were many flourishingly human activities during different historical periods that were developed in ancient Juyan Oasis in the downstream of the Heihe River Basin. A large number of historical ruins that reflect past human activities preserved between numerous of the nebkhas and sand dunes. In this study, combined high-resolution remote sensing imageries with in situ truths investigated during the fieldwork, certain unknown ruins were identified according to the image features of historical ruins that appear in remotely sensed data, which were undiscovered during the previous field archaeological investigations and unreported in the past public literatures. Almost all of the newly discovered ruins that were identified using remote sensing images are distributed in the Lvcheng and BJ2008 surroundings. Newly findings supplement the missing gaps that were not taking into account during the previous field surveys.

1. Introduction
Archaeology is named to explore and study the relics and ruins that were left behind through a variety of past human activities, in order to research and understand the conditions of history and human activities that happened in those ancient society. Remote sensing archaeology is namely the use of modern remote sensing techniques to explore various marks that represent the human activities of past thousand years in the legacy of the Earth’s surface from the air. Archaeology with remote sensing was firstly used to the study of airborne archaeological sites with balloon by British scientists in the early 20th century, and it was further attention and development in heritage conservation during the World War II and the post-war rebuilding and economic development (Nie, 2009). From the 1950s of the artificial satellite successfully launch to the early 21st century, the rapid development of a variety of satellites for earth imaging and information technology provide a new platform for space remote sensing archaeology. Plentiful of remote sensing technology for all types of archaeology provides a rich source of data and multiple research approaches, which play an important role in remote sensing archaeology at home and abroad (McCauley, 1982; Clark, 1998; Philip, 2002; Goossens, 2006; Rowlands, 2007). Compared with traditional field archaeology, remote sensing technology can be achieved to conduct research from whole to part, but also can supply information for some inaccessible or difficult to access regions. It will play a more important role in future archaeological due to its many advantages.

Silk Road is an essential communication channel of many human activities and cultural exchanges between ancient China and the West. Most part of the land Silk Road is covered with arid climate environment. As the most important water resources in arid region, inland river basin give birth to oases civilization, and where is the primary place for human activities and agricultural production from ancient to modern (Zhang, 2001; Fan, 2002; Xie, 2009; Qin, 2012). However, many oases, with good ecological environment and suitable for human survive in the past, had become to desert due to many factors, and a large number of ruins of ancient human activities stay. These archaeological ruins is the direct evidence and first-hand documents when carrying out the research on historical human activities and environmental change (Fan, 2002; Xie, 2009; Qin, 2012; Hou, 1964; Zhu, 1983; Li, 1990; Liu, 2010; Turner, 1974; Alizadeh, 2004; Yu, 2012). Because of the extreme climatic characteristics with drought and less precipitation and large evaporation, a large number of ruins still keep in the desert after thousands of years. These ruins is the most important data for the
study on the historical human activities and the process of oasis environmental change.

Heihe River Basin is one of the major arid inland rivers of the western China. Ejin Oasis is the downstream for the modern river, where the principal place to serving human’s lives and production. While the ancient Juyan Oasis is the river terminal during historical period, which is located southeast of the Ejin Oasis (Figure 1). Historical and archaeological discoveries indicated that there was lush vegetation and good environment in ancient Juyan Oasis. And there were also prosperity human activities during different historical periods. However, this oasis is completely desert, and plentiful of ruins and relics are the witness of the past human flourishing activities. It can do nothing for traditional field archaeology to some smaller targets hidden in countless sand dunes and nebkhas due to the oasis severe desertification. In addition, it is difficult for traditional archaeological field surveys to reach those areas that intensive sand dunes and nebkhas stopping the flow into the vehicle due to the serious sand erosion in the sub-region of the oasis. There are some advantages for remote sensing application in archaeology: observation from aerial avoiding the influence by terrain and topography, taking into account anywhere of the study area, and identifying the small ruins hidden in the sand dunes and nebkhas. Several of remote sensing images are comprehensively used to identify the historical ruins that were difficult to find in previous traditional field investigation. They enrich the archaeological information to a certain extent. It confirms that remote sensing technology can play a significant role in distinguish the small ruins in desertified environment. This study provides new quantitative evidence to further understanding of the relationship between human beings and nature in arid desert environment.

![Geographical location of the study area](image)

2.2 MATERIALS AND METHODS

2.1 Data sources

Besides collecting the archaeological reports officially published of the study area, two kinds of remote sensing imageries with high resolution were also used in the present study. As the first space satellite reconnaissance program, CORONA was deployed in 1958. The camera, which was equipped with KH-4A, obtained early high-resolution images at a resolution of approximately 3 m for the covered parts of China from August 1963 to September 1969. As access to an earlier era, the historical ruins is preserved better due to their less influence by early environment. These images served as an earlier important data source in this study. The CORONA images from September 29, 1969 were ordered and acquired from the USGS for the study and were primarily used to identify the unknown ruins. Because of its black and white photo, the appearance for some ruins are not enough outstanding, which features are not obvious. GeoEye images are very high resolution satellite data, and they were obtained from the Google Earth, which is a virtual global map service that contains several types of satellite images with different spatial resolutions. In the current study, GeoEye images from Google Earth for the study area have a resolution of 0.5 m, and the acquisition dates were March 28, 2010 and April 28, 2010. These images were primarily used as supplement to distinguish and extract the locations of the historical ruins. GeoEye images become the most important source to discriminate the ruins from the desertified environment, which lie in their false color composition and higher spatial resolution. The Landsat-Enhanced Thematic Mapper Plus (ETM+) images from May 28, 2002 were acquired and incorporated into this study, which were used as background for mapping, and analysing the environmental changes in the study area.
Several remotely sensed data were used in the current study, and preprocessing was required for these images to distinguish the ruins more accurately. Geometric corrections to the images were carried out using ground control points (GCPs) from the field investigations. The GCPs includes selected important sites and obvious targets (e.g., crossing points of rivers or discovered ruins). Next, the mosaicked images from the CORONA and GeoEye data were obtained using image processing software that applied the multi-scene images. The images used for this study were clipped with the boundary of the study area. Image enhancement was the last operation executed in order to improve the visibility of archaeological features on satellite data. Standard deviations and histogram equalizations were calculated for all of the images to highlight the image features of the ruins, particularly for the early black and white satellite images from CORONA.

2.2 Methodology

Archaeological documents, remote sensing data and field investigation are comprehensively used to distinguish the historical ruins in desertified environment. Previous archaeological reporters are primarily used to confirm and analyze the spatial distribution of the discovered ruins during the past surveys, which can help determining the target area where unknown ruins probably existing in the current oasis. The unknown ruins are primarily identified and extracted by indoor remote sensing data. Field investigation is for validating the accuracy of the interpreted results by indoor remotely sensed imageries, and obtaining other relevant information about the unknown ruins.

Historical ruins almost belong to artificial structures, which have fixed shapes and contour features. There are different conditions for the historical ruins in the desert: some are completely covered by sand dunes or nebkhas, while others expose to wind eroded land and surround by sand dunes and nebkhas. All the above mentioned information in remote sensing images are performed with regular geometric texture features, e.g. square or polygon. Additionally, shadow features will perform for some building with walls. These geometric textures and shadow features are the most important basis for the archaeological application with remote sensing data.

After analyzing the spatial distribution of the discovered ruins, we determined the approximate range of unknown ruins, where key areas are to conduct remote sensing archaeology. According to the typical imagery features of the historical ruins, we identify and extract the possible ruins by visual interpret. Then, we carry out the field investigation to validate the indoor interpreted results and observe the environment of the ruin surroundings.

3. Results and discussion

3.1 Spatial distribution of historical ruins

3.1.1 Distribution of discovered ruins

There were many outdoor adventures and archaeological investigations in Juyan Oasis during latest one hundred years since the 20th century to the 21st century, and a large number of historical ruins of human activities had been found (Figure2).

![Figure 2. Spatial distribution of the historical ruins](image_url)

As seen from Figure 2, mostly of the historical ruins that were discovered previously are mostly distributed in the northern region of the oasis, and some of them are distributed in the southern region.
In addition, a small number of the ruins are dispersed around the Gobi desert. In the view of spatial distribution of the surrounding ruins for each important city site, there are a large number of ruins distributed around the city sites of the northern oasis, such as K710, K688, and K749, and many ruins are dispersed around the city sites of K799 and Lvcheng that located in the southern oasis. However, the historical ruins around the Lvcheng are mostly distributed in the west, while there is nothing in the eastern and southern part of the city. And, there is also no ruins found around the BJ2008 site. Generally, a large number of small sites should distribute around the important city site because that many human activities performed around the large city site during the historical periods that were dominated with agricultural events. According to the archaeological surveys, BJ2008 site was built in the Han Dynasty, which is one of the largest city sites in the present discoveries (Sohma, 2009). It is an important area for Lvcheng site to have inhabited human activities at multiple historical stages, and there was prosperity agricultural settlements (Li, 1991; Li, 2003). According to the above mentioned evidence, we confirm that some unknown ruins have still undiscovered around BJ2008 and Lvcheng sites, in where the interested sub-area to conduct archaeological application with remote sensing.

3.1.2 Spatial pattern of newly discovered ruins
As is seen from Figure 2 about the spatial pattern of the newly discovered ruins, most of the ruins that were identified by remote sensing data are distributed in the northeastern part of the Lvcheng and BJ2008 surroundings, which both located in the south oasis. Furthermore, a few of newly discovered ruins are scattered around the K799 site and other region of the northern part of the oasis. The newly discovered ruins by remote sensing data supplement the spatial distribution of the missing remnants that were not discovered during those previous traditional archaeological surveys. These ruins ensure that many human activities are distributed around each important city sites. In particular, they update the missing information of the historical human activities around the Lvcheng and BJ2008 sites.

3.2 Field investigation and validation
Desertification results in complex surface shapes and complicated landforms. Image information appeared in remote sensing data is incomplete due to dilapidated ruins by sand dunes and nebkhas. Thus, the distinguished results based on imagery features need to be validated through field and in site observation in order to determine the accuracy and reliability of the newly discovered ruins. In addition, some apparent characteristics of the detected ruins can be displayed on remote sensing images, e.g. shape, texture, shadow, size, etc. But we do not know other attributes by remote sensing data, such as building materials, construction mode, ground relics and current conditions, which need to be obtained from field investigation.

![Figure 3. Spatial distribution of the validated sample ruins](image-url)

In this study, 15 samples of the newly discovered ruins are selected to conduct the field investigation and validation (Figure 3). By detailed comparison with the results of the in site truths, we found all the newly discovered ruins using remotely sensed data are built by man-made structures. Furthermore, according to the building materials and structured skills that were investigated during the fieldwork, as well as the ground relics surroundings, it is speculated that almost all of the newly discovered ruins were primarily built and used in the Western Xia and Yuan Dynasties (A.D. 1028-1375), while only a few of them should be the Han Dynasty.
There are different construction methods and area as different types and usage for the historical ruins. The current conditions of the ruins vary with their different locations and environments. According to the image features exhibited in remote sensing images, current size, ruin types, and site surroundings, 3 samples from the field investigated ruins are selected to show and compare their image features with in site characteristics (Figure 4).

Figure 4. Image features and in site truths of the ruins

4. Conclusion
In this study, some small historical ruins that were not discovered previously were identified and interpreted using remote sensing data in ancient Juyan Oasis. About 70 historical ruins were newly distinguished by remotely sensed data, and almost all of them are distributed in the Lvcheng and BJ2008 city sites of southern part of the oasis. These newly discovered ruins were primarily built and used in the Western Xia and Yuan Dynasties according to their constructed methods investigated during the field surveys, expect for a few of them are the Han Dynasty. Additionally, the newly discovered ruins supplement the missing relic information around the Lvcheng and BJ2008 city sites. Furthermore, newly discovered ruins greatly enrich the archaeological information that represent the ancient human activities in Juyan Oasis. It further proved that remote sensing technology can play a significant role in identifying small targets in desertified environment. In future, microwave remote sensing data with high resolution is expected to play a more important role to explore the historical ruins in the desertified environment.

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