Ground penetrating radar exploration at archaeological site in Shi Village, Xia County, Shanxi Province

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Abstract. With the rapid development of city construction, it's necessary to make archaeological exploration process more convenient, efficient and undamaged. As a result, some geophysical methods begin to be used firstly to find anomaly roughly during exploration. Ground penetrating radar (GPR), as a non-destructive and high-resolution method, should be an effective method in relatively shallow archaeological exploration. To verify the effectiveness of GPR, this paper mainly discusses the application of a combining method of GPR and Luoyang Spade – a traditional archaeological method at pre-Qin period site in Shi Village, Xia County, Yuncheng City, Shanxi Province, used GPR to find the anomaly area, then used Luoyang Spade to excavate to verify. This method can greatly shorten exploration time and reduce damage of culture relics.

1. Introduction

Xia County locates in Yuncheng City, a southwestern city of Shanxi Province, where in the juncture of Shanxi Province, Henan Province and Shaanxi Province. Shanxi Province is an important area where Chinese civilization originated, with lots of cultural relics from Paleolithic Age to Qing Dynasty, which made it significant in Chinese archaeological history. The southern Shanxi is the most archaeologically significate area, where archaeologists found many archaeological sites. The first scientific archaeological excavation organized by Chinese was in Xiying Village, Xia County in 1926, found the cultural relics of Yangshao Culture, an important Neolithic Age culture in the Yellow river basin [1,2]. In 1956, lots of cultural relics of Eastern Zhou Dynasty were found in Houma City, near to Yuncheng City, and experts confirmed Houma was the site of Jin State [3]. In 1962, a huge Western Zhou site was found in Houma, which was named Qu Village – Tianma site, this site was excavated in 1980s - 1990s, found lots of cultural relics of Western Zhou Dynasty and Han Dynasty, including Jinhou Tomb [4]. In 1950s, Dongxiaifeng site was found in Dongxiaifeng Village, Xia County, the site was excavated in 1970s, where archaeologists found the cultural relics of Longshan period, a late Neolithic Age period, Xia Dynasty and Shang Dynasty [5,6]. The sites mentioned above are some great discovery near to Xia County. In addition, one Song Dynasty tomb and three Jin Dynasty tombs were found in 1998, 2007, and 2010, respectively during construction in Xia County [7]. In 2001, the kiln site of the Han Dynasty at Shifeng Village, Xia County was excavated. In 2006, related department excavated Yuan Village site, which is closed to Shi Village, and found Yangshao, Longshan, Erlitou, Erligang, Han Dynasty and Song Dynasty cultural relics [8].

Through preliminary survey, Shanxi Culture Relics Bureau, cooperating with Jilin University, decided to choose Shi Village site from Qinglong River basin and Sushui River basin cultural relics sites as survey object. Before using Luoyang Spade to excavate, some geophysical methods, including
electrical resistivity tomography (ERT), ground penetrating radar (GPR) and aeromagnetic survey were used to get underground information, to delineate area of interest. This paper will discuss application of GPR in the archaeological work, firstly, describes the general situation of survey area, including position, surface condition, working mode, then uses processed GPR data to find possible anomalies, finally, uses excavating result to verify the effectiveness of GPR method.

2. General situation of survey area

2.1. Position and ground condition
Shi Village lies in Peijie Town, Xia County, Yuncheng City, Shanxi Province (Figure 1A). The survey area locates near to 209 National Rd.
The survey area is a deserted farmland, which is covered by wheat stubble generally, and there are also some trees and graves (Figure 1B). The ground condition is not good for GPR exploration, we have to pay attention to GPR data collection and processing to eliminate the impact of surface conditions.

2.2. Working mode
ERT and GPR exploration were used together. The survey area was a 150 m×140 m field. 31 main survey lines were arranged, with length of 140 m and line interval of 5 m. In order to label conveniently, survey lines were numbered from 10 to 70, with interval of 2, such as 10, 12, 14 … 68, 70 (Figure 1B). The arrows show the survey lines direction, from 0 m to 140 m.
Towed radar with manual mark tool and antenna with central frequency of 500 MHz were used during this GPR survey. Working mode of one person towing the antenna roundly as well as marking and one person concerning about the real-time collected data as well as recording ground conditions. GPR is a high frequency electromagnetic (EM) method, with a transmitting antenna to transmit EM wave and a receive antenna to receive reflected wave from underground reflector. GPR uses two-way travel time and underground EM wave velocity estimated by permittivity to get the depth of reflector. Nowadays, GPR is often used in archeology because of nondestructive, convenience and high-resolution features. Before collecting data, parameters needed to be set in GPR system. Underground relative permittivity \(\varepsilon_r\) was set to be 8.15 according to soil condition (Kang et al., 2015), time range \(t_r\) was set as 100ns to make sure profile depth displayed \(L\) was deep enough, which was calculated by radar system automatically through Equation (1)-(2):

\[
v_g = \frac{c}{\sqrt{\varepsilon_r}} \quad (1)
\]

\[
L = \frac{v_g \cdot t_r}{2} \quad (2)
\]

where \(v_g\) denotes propagation velocity of EM wave underground, \(c\) is propagation velocity of EM wave in the air. \(L\) was 5.2 m, which should be pay attention was that \(L\) was not effective detecting depth, the experienced effective detecting depth of 500 MHz antenna is about 2-3 m (Zhao et al., 2003). The data whose depth deeper than effective depth was invalid.
3. GPR data processing
RADAN 7, a GPR data processing and interpretation soft was used in data processing. Firstly, the data were normalized according to the marks because it was collected by towed GPR with variable speed, normalization can equalize the spaces between every two neighboring marks, converse the collecting tracks to distances. Secondly, the normalized data was filtered, including background removal, horizontal filtering and vertical filtering ranging from 100 MHz to 650 MHz, to eliminate noise during data acquisition. Thirdly, removing excessive gain during data collecting process to and save the file or reverse file according to the GPR data collecting direction. Figure 2 shows the partial GPR data of the line 40-3 processed by this procedure.

Figure 1. Position of Xia County(A), Survey area (B), and amplified area of interest (C).

Figure 2. Original collected GPR data with marks (A), GPR data processed result after normalization (B), GPR data processed result after normalization and filtering (C), GPR data processed result after normalization, filtering and gain removing (D).
4. GPR data interpretation

A quasi 3D GPR data are built using 2D data acquired along parallel survey lines. The z axis represents depth, the x axis is the orientation along the survey lines, and the y axis is the orientation perpendicular to survey lines. The depth of the 3D model is about 5.2 m, with effective depth of 2-3 m, the length is 115 m, and the width is 21 m, including 22 survey lines. Figure 4 shows z slices at different depth, 3 slices were chosen to be showed in this paper after viewing, including slices at depth of 0 m, 2 m, and 4 m. The 3 slices show underground situation.

![Figure 3. 3D GPR data display.](image)

![Figure 4. Slice of GPR data at z = 0 m (A), slice of GPR data at z = 2 m (B).](image)

GPR response includes response of underground reflectors, vegetation and interference like tombs on the ground. The shallower the slice is, the bigger the surface influence is. Figure 4 shows the GPR response variation with depth. Figure 4A is most affected by the surface, referenced with profile data, the relatively larger GPR response in the black dotted rectangle in upper right corner mainly affected by ground, so data at this position may has greater error when doing further slice interpretation. In Figure 4B, abnormal response in black dotted circle are generated by recorded interference on the ground, which shouldn’t be considered as anomaly. Inferred anomaly area is delineated by black solid rectangle. Considered with Figure 4A and profile data, some main anomalies are inferred, which are delineated by black solid lines in Figure 4B.

After GPR and ERT exploration, School of Archeology in Jilin University conducted archeological excavation in this survey area using Luoyang Spade, detailed excavated place is shown as Excavation Unit in Figure 5. Figure 5 shows partial excavation results in area of interest. Excavation units show detailed excavated position. Two wall bases and three grooves were found in excavated area, which at depth of 1.5-3.5 m. Compared with the result, inferred anomalies can conform to wall bases, because grooves and wall bases have partial overlapping, anomalies may be caused by wall bases or wall bases and grooves. This discovery proves the GPR result is effective.
5. Conclusion
GPR method was used for preliminary exploration in archeological survey in Shi Village, Shanxi Province. After data processing and interpretation, GPR data give the possible location of some archaeological targets.

Inferring geophysical results, archeologists chose several areas to excavate. In the area discussed in this paper, there were 38 excavation units. Two wall bases and three grooves were found in these units. Besides that, some relic fragments in the eastern Zhou period, Song, and Jin Dynasties were found in cultural layers. Excavation results has good correspondence with anomalies inferred by GPR data. This paper shows that GPR method is effective in archeological work.

Figure 5. Partial excavation result.

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