CHAPTER 1

INTRODUCTION

Ground-penetrating radar (GPR) is a high-resolution electromagnetic (EM) geophysical method that can accurately map the spatial extent of near-surface objects and archaeological features (Conyers, 2004). Changes in the matrix of a site can be mapped by GPR and ultimately images of those materials are produced. GPR uses the principle of propagation, reflection and scattering of EM waves to locate buried objects. The EM wave is propagated in distinct pulses from a transmitting antenna, reflected at buried objects, features, bedding contacts, or soil units, and detected back by a receiving antenna. Investigation depth of GPR instrument depends on transmitted energy, conductivity of earth material and EM frequency. High resolution data can be obtained using high frequency GPR antenna but such high-frequency EM wave can penetrate shallower than that of low frequency. GPR data may contain noise and extraneous reflection such as air wave, multiple reflections and point source, so raw reflection data must be cleaned up and adjusted in some way prior to interpretation. Common processing of GPR data is similar to that of seismic data processing, including distance normalization and trace stacking, zero-time correction, DC removal, background removal, amplitude scaling, low-pass filter, deconvolution and migration.

Advanced processing techniques such as attribute analysis is common in the seismic industry where sections are displayed with certain functions applied to the color rendering of their reflection signals (Chopra and Marfurt, 2007). Information about the relative reflectivity, amplitude, frequency and phase relationships have all been used in preliminary interpretation and obtain additional information about the subsurface directly from the seismic data. Numbers of seismic attributes can be applied to improve GPR data interpretation, for example similarity attribute, normally used to detect faults in seismic data can enhance boundaries between objects and surrounding material in GPR data (De Rooij and Tingdahl, 2002). Other attributes include energy, coherency, frequency and etc. All of them give different information and can be combined in certain applications. For visualization, time slice is a conventional technique used to display subsurface structures at specific time or depth. However, time-slice displays could be difficult to interpret where data are complicated. Iso-amplitude has also been developed to aid in 3D visualization of objects in GPR data.

1.1 Research Objective and Scope

In this thesis, attribute analysis is applied to GPR data acquired at two archaeological sites located in Chiang Mai City Area, Wat Pan Sao and Wiang Kum Kam. The goal of this thesis is to delineate and improve visualization of subsurface archaeological structures at the two sites using the GPR attribute analysis. The GPR data processing is done in VISTA® 2D/3D Seismic Processing Software version 7.0. OpendTect software is used for the attribute analysis and visualization.

1.2 Literature Review

Examples of application of attributes such as coherency were presented by Bahorich and Farmer (1995). Three dimensional (3D) seismic data were calculated for coherency and compared to common 3D seismic data. Coherency analysis revealed faults which were difficult to see by amplitude of 3D seismic cube especially the faults that ran perpendicular to strike. The coherency can be quickly used to provide a view of regional faulting. Javaheri Niestanak et al. (2007) detected faults in migrated 3D seismic data from the North Eastern oil fields (Khangiran) of Iran by using coherency attribute based on crosscorrelation and eigenstructure. Coherency attribute gave an indication of continuity between two or more seismic traces and can extract detail from the data cube with good efficiency both in synthetic and real data. The results illustrated that coherency attribute based on eigenstructure provided better detection of small faults with high resolution.

Forte et al. (2010) evaluated the GPR capability to identify rock layers related to sedimentary processes and features related to karstic or tectonic processes using data collected from abandoned limestone quarry. Attribute analysis related to amplitude and frequency and coherency were calculated. The results were integrated with direct outcrop information and applied in the imaging of a hydrocarbon reservoir analogue.

Böniger and Tronicke (2010a) performed a high-resolution 3D GPR survey to localize tombs inside medieval chapels situated in the state of Brandenburg, Germany, to improve archaeological target visualization, attributes (energy, coherency and similarity) were calculated based on information regarding data acquisition and processing. The results show significantly improved detail of archaeological targets (tombs). The sensitivity of the similarity attribute to amplitude variations is favorable compared to the coherency attribute in order to obtain a more continuous image. Böniger and Tronicke (2010b) also integrated 3D GPR, magnetic and high-resolution topographic data at an archaeological site within the Palace Garden of Paretz, Germany to detect and locate the remains of ancient architectural elements. To visually enhance or isolate the features of interest, energy and similarity attribute were calculated. Shape and border of old temples can be identified by using these attributes. The results of the study show the benefit of acquiring and interpreting multiple data sets in archaeology. The results will be used to develop excavation and eventual restoration plans of the area.

Keach et al. (2010) succeeded in applying seismic attributes technique to GPR data obtained from 19^{th} century cemetery and Roman archaeological site. Attributes used were connectedness (geoanomalies), semblance (dissimilarity), volume rendering (transparency visualization) and waveform classification. The results from the two locations demonstrated the value of semblance, volume rendering, geoanomaly computations and waveform classification in delineating subtle boundaries and soil disturbances. The authors suggested that combination attributes or visualization techniques should be used to reduce the uncertainty of interpretation.

1.3 Data Set

Two GPR data sets used for attribute analysis in this thesis were acquired at Wat Pan Sao in 2010 and Wiang Kum Kam in 2011 during the Geoscientists Without Borders (GWB) project held in Thailand. The GPR data surveys were performed using a Subsurface Interface Radar System-20 (SIR-20) with 200 MHz center frequency antenna manufactured by Geophysical Survey System Inc. (GSSI) (Figure 1.1). The data were recorded with 1 m reference marks for accurate distance correlations. These data sets were applied time-zero correction during recording.

(a) (b)

Figure 1.1. (a) GSSI SIR-20 GPR system with (b) 200 MHz antenna.

1.3.1 Wat Pan Sao Data Set

Wat Pan Sao is located outside and west of the Chiang Mai City Moat (Figure 1.2). It was constructed during the reign of the Mangrai Kingdom. During the reign of King Phaya Yoo (AD 1336-1355) and King Phaya Kue Na (AD 1355-1385), a small pagoda was built in the Present-day area of Wat Pan Sao. Subsequently, Wat Pan Sao was destroyed by wars and was used as a field for feeding elephants. Some of its old area was intruded and portioned out to private owners. In 2007, the Malaria Curing Center occupied the area and later gave the area back to the office of the Buddhism of Chiang Mai. Since then, it has been a place for religious activities.

An excavation was performed by archaeologists east of the pagoda revealing old brick floor at a depth of about 20 cm overlaid by floodplain sediment and landfill layers (Figure 1.3). An area in front of the eastern side of the old pagoda is the suspected location of a buried old Buddha hall which may extend from the excavation point to the west and would be imaged by the GPR survey.

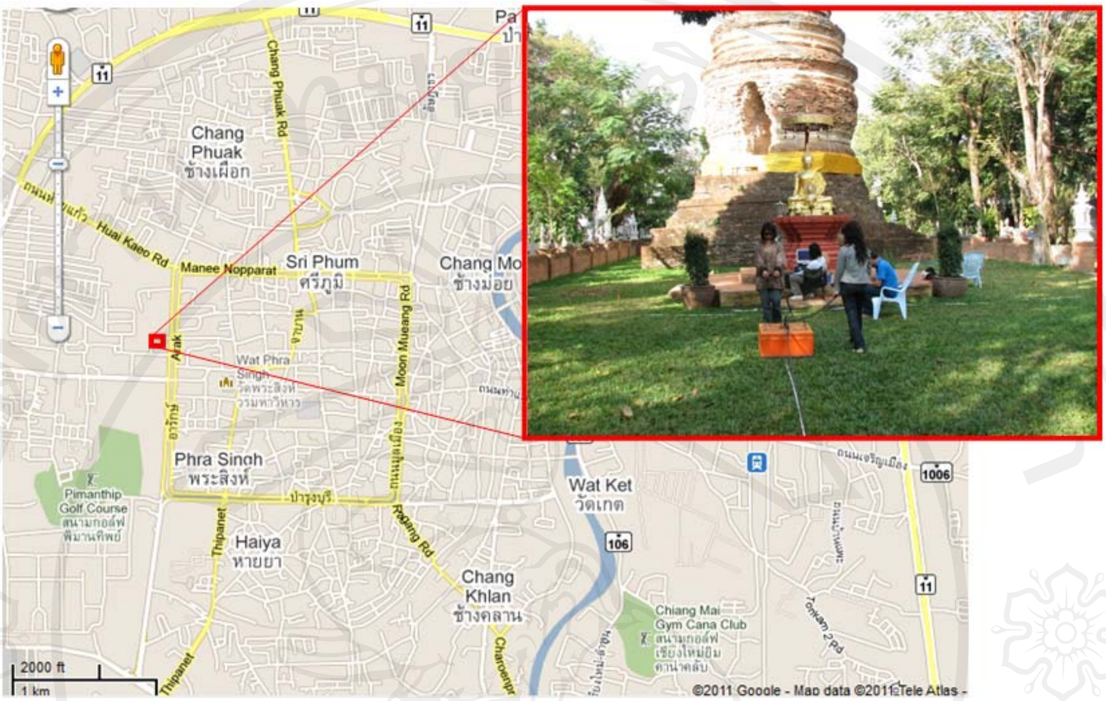

Figure 1.2. Survey area at Wat Pan Sao. (From Google Inc, 2012).

Figure 1.3. Excavated area near the study survey area at Wat Pan Sao. (From Department of Fine Arts, In Press).

The GPR data at Wat Pan Sao were acquired in front of the old pagoda (Figure 1.3) covering an area of 14×18 m^2. The data were recorded with 99.45 ns record length, 0.195 ns sample rate, and 0.05 m trace spacing. The data set included 35 parallel profiles in the north-south directions (inlines) and 26 parallel profiles in the east-west directions (crosslines) with 0.5 m profile spacing. Figure 1.4 presents the GPR profile orientation at Wat Pan Sao.

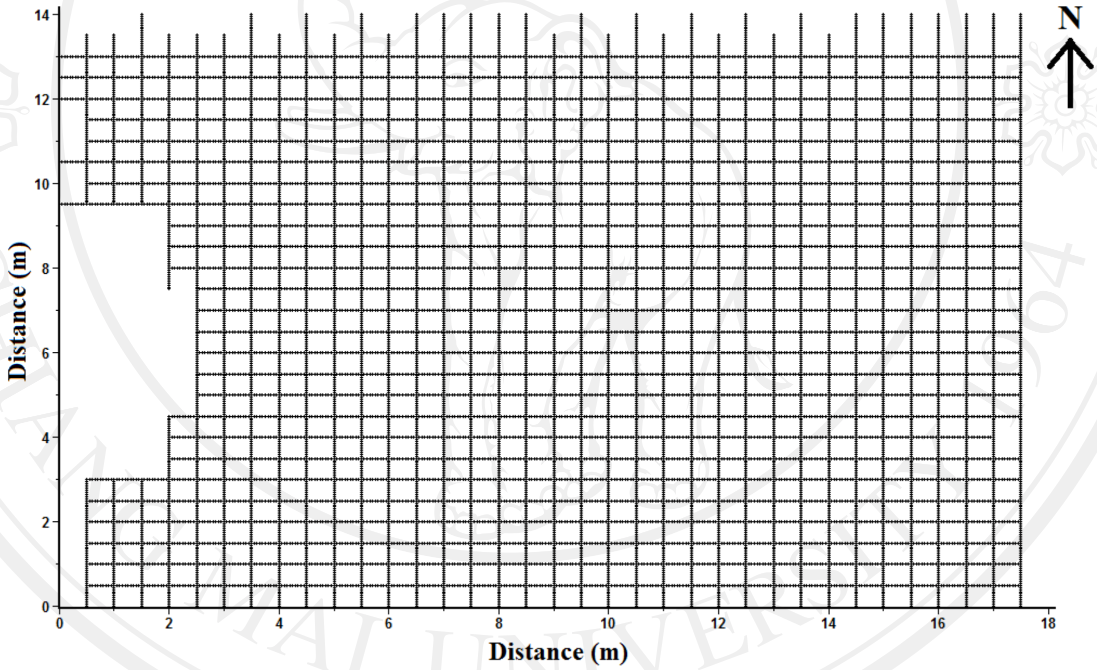

Figure 1.4. Wat Pan Sao GPR survey line orientation.

1.3.2 Wiang Kum Kam Data Set

Wiang Kum Kam is situated on the bank of the Ping River, southeast of Chiang Mai city (Figure 1.5). It was built in 1288, when King Mengrai relocated the Lanna capital from Chiang Rai. Since the city was encountered by several flooding during rainy seasons, in 1296, the capital city was moved to a new site stretching from the foothills of Doi Suthep to the Ping River and declared Nopphaburi Srinakhon Ping Chiang Mai, the permanent capital of the Lanna kingdom. Geology of Wiang Kum Kam includes widespread Quaternary alluvium layers composed of gravels, sands, silts and clays. Archaeological structures were buried at more than 1 m deep by several floodings. The GPR survey was performed on the eastern side of an old brick wall oriented in east-west direction (Figure 1.6). This wall may extend to the eastern side.

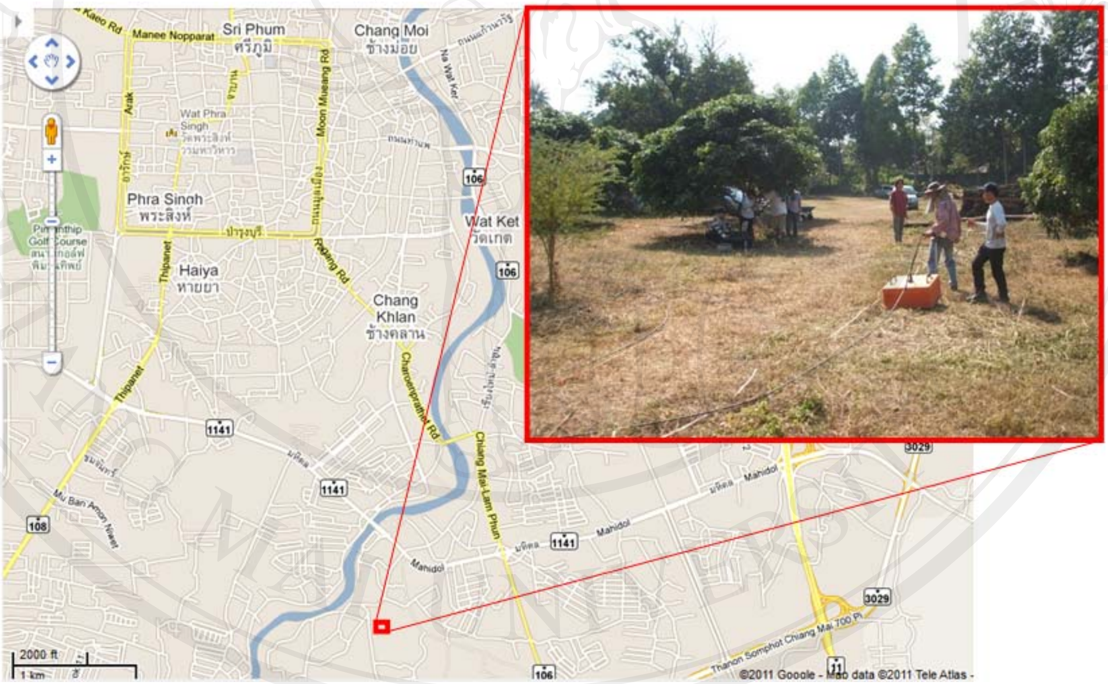

Figure 1.5. Survey area at Wiang Kum Kam. (From Google Inc, 2012).

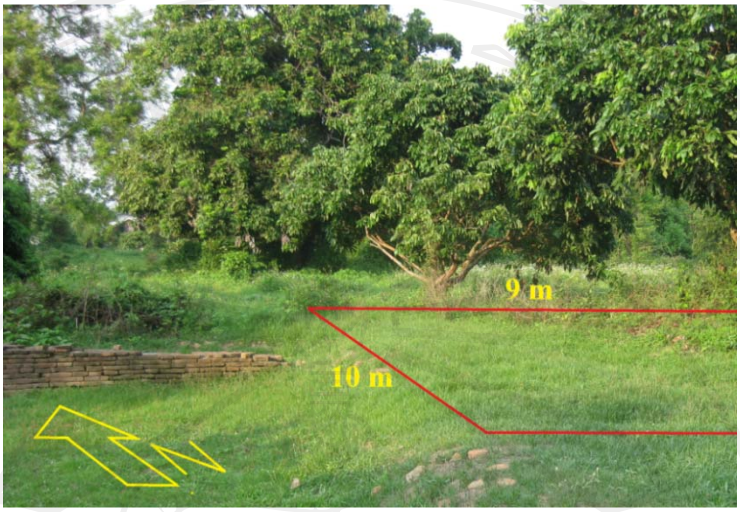

Figure 1.6. Survey area on the eastern side of old brick wall in Wiang Kum Kam site.

The GPR data at Wiang Kum Kam were collected in Wat Phaya Meng Rai covering an area of 9×10 m^2. The data was recorded with 99.45 ns record length, 0.195 ns sample rate, and ~0.01 m trace spacing. The data set comprises 19 parallel profiles in the north-south direction with 0.5 m profile spacing. Figure 1.7 shows orientation of the GPR profiles at Wiang Kum Kam.

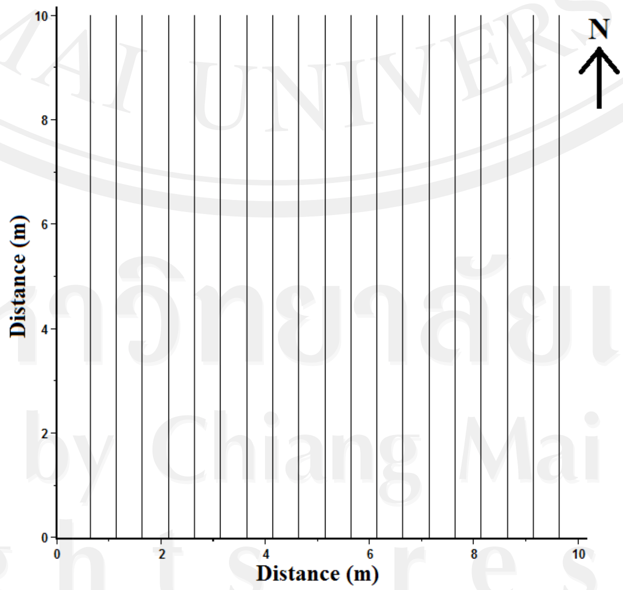

Figure 1.7. Wiang Kum Kam GPR survey line orientation.