Investigation of El Castillo, Chichén Itzá using non-destructive Ground Penetrating Radar techniques

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Abstract

Chichén Itzá was one of the largest pre-Columbian cities built by the Maya people of the Terminal Classic period (c. 830-950 A.D.). The archaeological site is located in Tinúm Municipality, Yucatán State and is one of the most visited archaeological sites in Mexico. The El Castillo pyramid serves as a monumental representation of the Mayan calendar. Archaeologists have investigated the artefacts of Chichén Itzá and the visible structural properties of El Castillo, however, there have been limited investigations of the internal properties of El Castillo. In 2015, researchers, using electrical resistivity, discovered a large cenote beneath El Castillo. In 2016, a 10 metre tall pyramid within two other structures was discovered that comprise the full pyramid. Aside of electrical resistivity techniques, there has been limited investigation of pyramids using non-destructive Ground Penetrating Radar (GPR) techniques.

Introduction

We propose the use of GPR to survey El Castillo and obtain information on the internal properties of the structure. Our work considers using an adapted Utsi Electronics GroundVue 7 GPR with 40MHz centre frequency antenna, total robotic station positioning and adapted transmitter-receiver time synchronisation using fiber optic cable. We produce simulation models based on findings from previous research where El Castillo is comprised of three pyramid structures. Our model is illustrated in Figure 3 where we perform GPR measurements through the structure in the horizontal x and z axes. The transmitter and receiver are time synchronised and moved in one metre increments. The model assumes internal structures consisting of limestone and sand. The purpose of this modelling is to show typical GPR results based on the structures size and materials before carrying out a GPR survey.

Proposed Survey and Modelling

In order to survey El Castillo, we must be able to move a GPR across the surface of the pyramid. One problem we envision is the step angles because those are not horizontal. We propose the use of climbing equipment, hoists and ropes. The Utsi Electronics GV7 system is a 'snake' antenna, this is because at 40 MHz centre frequency, the antennas are approximately 9 metres in length. We propose using fiber optic cable to time synchronise the GPR's transmitter and receiver which are placed on opposite sides of the pyramid during survey. This mitigates the problem of using cables which would interfere with the radar image. Furthermore, all climbing equipment, hoists and ropes must also be non-metallic. The pyramid must be surveyed in both x and z directions in order to generate the two-dimensional tomography image.

We use Sandmeier ReflexW processing software to generate two-dimensional tomography images for expected cross-section scenarios. Our model is illustrated in Figure 3 where we perform GPR measurements through the structure across the x and z horizontal axis. We transverse the transmitter and receiver in one metre increments and the model assumes internal structures consisting of limestone and sand. The basic processing steps can be summarised:

1. Create representitive scale model of El Castillo.
2. Generate GPR data and store this with corresponding position data.
3. Extract 'travel time' from each transmitter-receiver GPR measurement.
4. Generate Tomography image using Simultaneous Iterative Reconstruction Technique (SIRT).

We construct the models in ReflexW and use a defined geometry file to transverse the GPR transmitter and receiver in x and z horizontal directions. Time-travel is 'picked' for each measurement using an auto-pick function within ReflexW. This task can be complex because the automatic picking tool may not always pick the correct times within the data. Figure 1 illustrates first-arrival 'picking' for a single GPR dataset. We evaluated a sample set of travel-time data in order to verify correct picking and adjust parameters to achieve the desired result. Following first-arrival 'picking' of the complete data set, we combine this data into a single 'pick' file as illustrated in Figure 2. Pick data is then used to produce tomography images for various modelled scenarios. Tomography allows the automatic adaptation of synthetic travel-time data to real data based on a tomographic algorithm. ReflexW uses an iterative adaption Simultaneous Iterative Reconstruction Technique (SIRT) algorithm. Estimated travel-times are compared to real ones and model changes are automatically derived from the travel time residuals. This procedure is repeated based on the changed model. After a pre-defined criterion is met, the complete process is stopped.

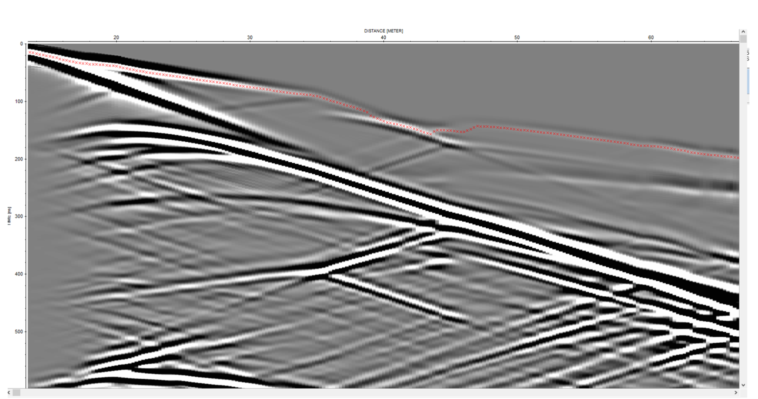

Figure 1: Example of automatic first-arrival 'picking' process of GPR data in ReflexW. First-arrival denoted by red crosses.

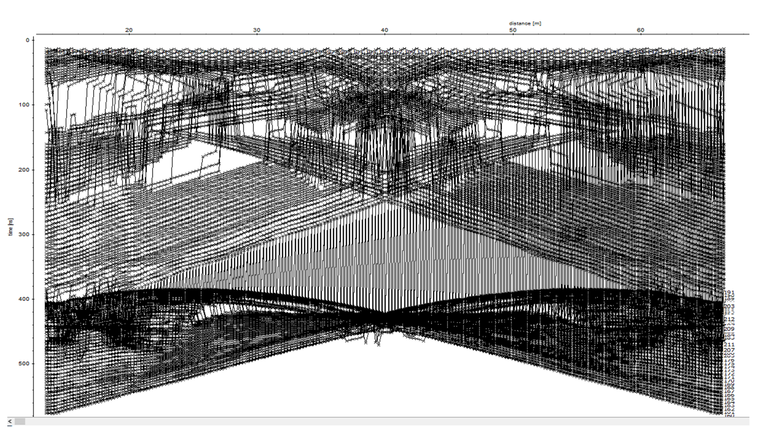

Figure 2: Example of time travel data generated from basic El Castillo model. Transmitter-receiver transvers across single side.

Results

We use ReflexW to generate tomography results for various senarios. Figure 3 illustrates a basic model of a structure consisting of two materials sand and limestone. This model has been developed to resemble the expected structural characteristics of El Castillo with equivelent dimensions. Figure 4 illustrates the tomography result obtained by performing GPR measurements through the structure using a 40 MHz centre frequency GPR and transverse transmitter-receiver at one metre increments across the structure. The result is based on 20 iterations and averaging over 10 points in both x and z axes. The material boundaries can be clearly seen in the tomography image defined by the change of contrast. Figure 5 illustrates a more complex model involving the additional stairs of El Castillo and a 10 m^2 void within the structure at the lower right-hand quadrant. Here we aim to replicate 'voids' as found in the Egyptian pyramids and determine if GPR can be used to 'see' those features within the pyramid structure. Figure 6 shows the corresponding tomography image, the result is based on 20 iterations and averaging over 10 points in both x and z axes. Transverse of the transmitter and receiver around the stairs of the model show a negative result on the tomography result.

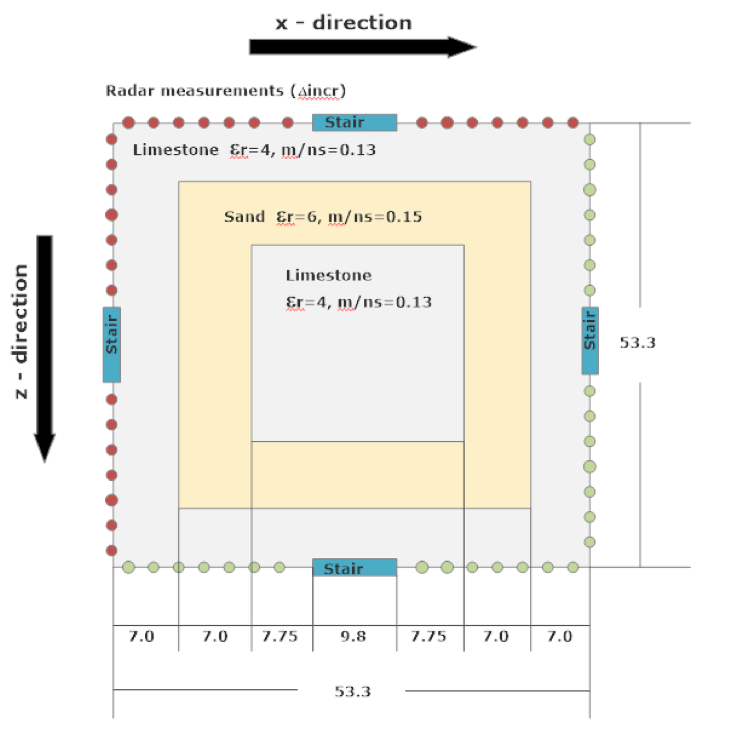

Figure 3: Cross-section model used to evaluate the use of GPR to investigate internal properties of El Castillo. Three internal structures consisting of limestone and sand. GPR transmitter (green) and receiver (red) positioned at opposite sides of the pyramid and incremented at one metre spacing. This is performed for both axis of the two-dimensional model and transmitter and receiver are then switched in position.

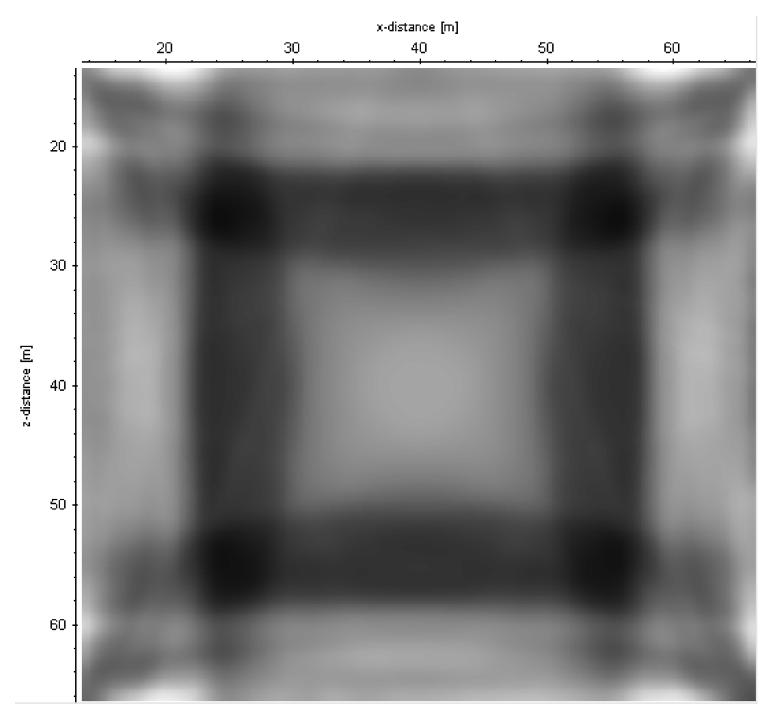

Figure 4: Tomography result obtained from El Castillo scale modelling in ReflexW. Result based on 20 iterations and averaging over 10 points in x and z axes. Three internal structures can be seen by the material boundaries, illustrated by darker and lighter areas.

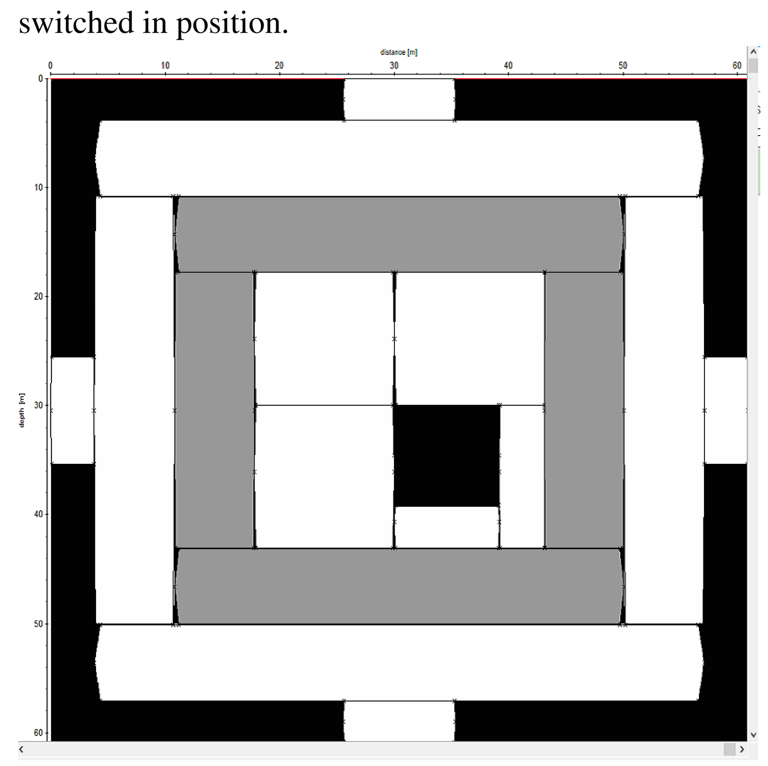

Figure 5: Cross-section model used to evaluate the use of GPR to investigate internal properties of El Castillo with a void. Three internal structures consisting of limestone and sand. GPR transmitter and receiver positioned at opposite sides of the pyramid and incremented at one metre spacing. This is performed for both axes of the two-dimensional model and transmitter and receiver are then switched in position.

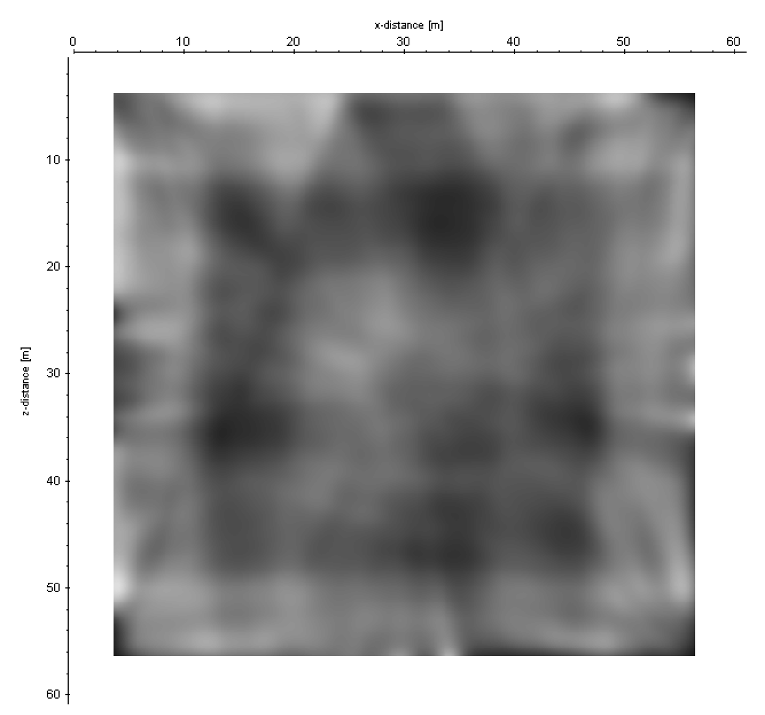

Figure 6: Tomography result obtained from El Castillo scale modelling in ReflexW. Result based on 20 iterations and averaging over 10 points in x and z axes. Three internal structures can be seen by the material boundaries, illustrated by darker and lighter areas.

Conclusions

- Using adapted Utsi Electronics GroundVue 7 GPR, material boundaries within the El Castillo pyramid structure may be visable.
- Precise position information and good transmitter receiver geometry is fundamental to obtain accurate tomography images.
- Materials' properties are fundamental in the ability of GPR to penetrate the structure of interest.

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