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Determining the Mass Grave Delineation in Sandy Soils Using Ground Penetrating Radar, a Laboratory Experiment

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Abstract

Identifying the mass graves' boundaries is a significant step in mass graves' preparatory procedures. A laboratory experiment was conducted to determine the effectiveness of ground penetrating radar in identifying mass graves and delineating their boundaries in sandy soil. A GSSI SIR-3000 GPR system with a 1.5 GHz antenna was used for the experiment. Eight GPR profiles were run over a 0.16m-deep wooden sandbox that contained buried bones to simulate the mass grave. All GPR profiles were processed using zero time, background removal, and filters to produce clearer, more accurate, and interpretable GPR data. This geophysical technique showed its assistance and effectiveness in locating the mass grave and tracking its delineation within sandy soils (desert environment). It was easy to locate the boundary between the simulated human remains (bones) and the surrounding materials (sand) due to the differences in their dielectric constant due to the chemical and physical differences that will convert to different reflections. Changing the antenna configurations (polarizations) in the GPR survey over the simulated target showed a clear difference in the reflection or the clarity of the "target". The calculated depth of the buried bones was very close to the actual depth. This novel application of the GPR will help in Iraqi mass grave investigation, recovery and excavation in desert environments.

Keywords: GPR; Mass graves; Boundary; Forensic, Sand; Dielectric constant

تحديد حدود المقابر الجماعية في الترب الرملية باستخدام الرادار المخترق للأرض، تجربة مختبرية

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الخلاصة

يعد تحديد حدود المقابر الجماعية خطوة مهمة للغاية في اجراءات الكشف عن المقابر الجماعية. تم إجراء تجربة مختبرية لفحص مدى فعالية الرادار المخترق للأرض في تحديد المقابر الجماعية وتتبع ترسيمها وامتداداتها في التربة الرملية. لإجراء التجربة، تم استخدام الرادار المخترق للارض نوع GSSI SIR-3000 مع هوائي بتردد 1.5 جيجا هرتز. تم عمل ثمانية مقاطع GPR على صندوق خشبي مملوء بالرمل مع عظام مدفونة على عمق 0.16 متر لمحاكاة مقبرة جماعية. تمت معالجة جميع مقاطع الـ GPR بتطبيق معالجة تصحيح وقت الصفر وازالة الخلفية والمرشحات للحصول على بيانات GPR واضحة وأكثر دقة وقابلة

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للتفسير. وأظهرت هذه التقنية الجيوفيزيائية فائدتها وفعاليتها في تحديد موقع المقبرة الجماعية وتتبع حدودها ضمن التربة الرملية (البيئة الصحراوية). كان من السهل تحديد الحد الفاصل بين البقايا البشرية المحاكية (العظام) والمواد المحيطة بها (الرمل) بسبب اختلاف ثابت العزل الكهربائي نتيجة الاختلافات الكيميائية والفيزيائية بين المادتين والتي ستتحول إلى انعكاسات مختلفة. إن تغيير توجيه الهوائي (القطبيه) في مسح الـ **GPR** على الهدف يظهر اختلاف واضح في انعكاس أو وضوح "الهدف". كان العمق المحسوب للعظام المدفونة قريباً جداً من العمق الحقيقي. سيساعد هذا التطبيق الجديد لـ **GPR** في تحديد المقابر الجماعية العراقية والتنقيب عنها وتحديد امتداداتها في البيئات الصحراوية.

1. Introduction

The typical definition of a mass grave was described by Skinner as a hole containing at least six individuals tightly together and placed randomly without any respect [1]. Some mass graves have

Seven hundred bodies; also, the mass grave may be divided into many secondary mass graves [1]. The mass graves can be found in unstable political countries with civil wars [2]; [3]; [4], countries that suffer from hunger like African countries, countries with pandemic diseases [5], as well as countries that are affected by the I and II World Wars [1].

According to the Bournemouth Protocol on Mass Grave Protection and Investigation [6], mass graves refer to the location or area that contains more than one human body remains buried, submerged, or scattered. Cases of mass graves showed that they had been filled with local soil (disturbed or uncompacted soil), town wastes, demolished buildings and broken bottles [7], so there are physical differences between the human dead bodies and the surrounding materials. One of the old mass graves that have been discovered is the Early Neolithic Linearbandkeramik (LBK) mass grave of Schöneck-Kilianstädten, Germany, from Early Neolithic Central Europe (5600–4900 cal BC) [3].

In Iraq, after the Saddam regime and after 2003, there are over 250 mass graves reported, and there are more, with over one million Iraqis part of them in mass graves [2]. Also, a report published in 2005 showed that the number of discovered mass graves in Iraq is 295, and this number has increased with time. Many of these mass graves were found in the Al-Muthanna southwestern desert of Iraq [8]. These mass graves are a result of many attacks such as 1983, 1986, and 1988 attacks against Kurdish people, including the chemical attack on Kurdistan village, the 1988 Anfal campaign where Iraqis were killed and then executed, then buried in mass graves in the desert sand, as well as the Shi'a 1991 uprising [2]. One of the most significant mass graves in Iraq is (the Al-Mahawil mass grave). It consisted of more than two thousand Iraqis [9]. The first mass grave in Iraq was discovered on May 2nd, 2003, near Al-Hilla (Al-Imam Al-Bakie village) [9].

Identifying and knowing the mass graves' boundaries is a crucial step in mass graves' preparatory procedures. It is challenging to locate the surface of the mass graves visually if they are covered by vegetation [7].

For the verification and the assessment (discovering) of the mass grave, satellite and remote sensing can help [1]; [7]; [6]. Due to the physical differences between the dead bodies and the surrounding material and the filled materials, in addition to the disturbance in the soil, geophysical techniques can help [10]. Nero and others, 2016 applied electrical resistivity tomography (ERT) to identify the delineation of some royal graves. The survey revealed heterogeneity in resistivity values, with rectangular anomalies indicating the presence of graves [11]. In 2014, Leblanc and others used airborne hyperspectral imaging (HSI) to locate single graves and airborne HIS to locate and distinguish graves [12]. In 2015, Dick and colleagues used multi-proxy geophysical techniques (GPR, EM, and ERI) to identify approximately 200 individual burials of the Yersinia Pestis plague epidemic "Black Death" [5]. Fernández-Álvarez et al. in 2016 used a 500 MHz antenna to detect a mass grave from Spain's civil war in a mountain terrain. The GPR effectively detected the mass grave as a zone of signal attenuation [4].

Doro and others in 2022 applied three geophysical techniques (EM, ERT and GPR) on simulated graves (1 mass grave, three single graves, and 2 monitoring empty graves of the same sizes) to see the changes in the ground properties (the electrical conductivity and the electrical resistivity); the authors concluded a presence of changes in the electrical resistivity and conductivity after burying the cadavers. Also, the GPR profiles revealed high-reflection subsurface contacts from shallow bedrock layers and small hyperbolas from rock fragments [13]. Doro and others in 2022 used electrical resistivity to detect ground electrical resistivity in graves; they observed a decrease in grave resistivity in the first two days due to soil aeration, followed by a decrease as a result of pores filling with leachates [14].

One of the well-accepted non-invasive geophysical techniques in many fields is the GPR [15]. It works in multiple frequencies (1-2000 MHz) of (radio) electromagnetic waves [16]. During the 1950s and for studying the ice-covered area, radio waves were applied for this application for the first time [17]. In the early 1970s, early application of the GPR was to investigate the non-ice areas [16]. The mechanism of the GPR is done by using two antennas to send the electromagnetic (EM) waves toward the ground via a transmitted antenna, while receiving the reflected signals via the second one, the receiving antenna. The GPR penetrating depth varies according to the subsurface characteristics and the system specifications, so the investigation depths are between 0 and 50m [18].
GPR has wide and various applications, including:
-Environmental applications [19];
-Archaeological applications [20]; [21]; [22]; [23]; [24]; [25];
-Engineering applications [26]; [27]; [28]; [29]; [30]; [31]; [32]; [33]; [34]; [35]; [36]; [37]; [38]; [39]; [40]; [41]; [42]; [43]; [44]; [45]; [46]; [47];
-Mineralogy [48]; [49];
-Hydrological applications [50]; [51]; [52];
-Agricultural applications [53];
-weapons and landmines detection [54]; [55];
-Biological applications [56]; [57]; [58]; [59]; [60];
-Forensic applications [61]; [62];
-Utility applications [63]; [64] and more many applications.
This study aims to study the effectiveness of the GPR technique with a 1.5 GHz antenna in identifying the mass grave delineation in sandy soils (desert environment).

2. Materials and Methods

To simulate a mass grave, some bones were placed in a wooden box with outside dimensions of 135, 59, and 53 cm in length, height and width, respectively, under a depth of 16 cm, as shown in Figure 1. The GPR system model GSSI-SIR-3000 was used to collect the data for this experiment with a 1.5 GHz monostatic antenna (Figure 2). Each seven ns scan was sampled at discrete 16 bits per sample and 1024 samples per scan. Data were filtered using bandpass filters (75 MHz high-pass and 750 MHz low-pass filters). The edges of the box reflect electromagnetic waves; to avoid unwanted side reflections, the scan began about 15 cm from the edges.

Knowing the exact value of the sand dielectric constant is fundamental to calculate a more accurate target depth, so Steven's Soil Sensor (Figure 3) was used for this measurement; the sand dielectric constant was 2.6.

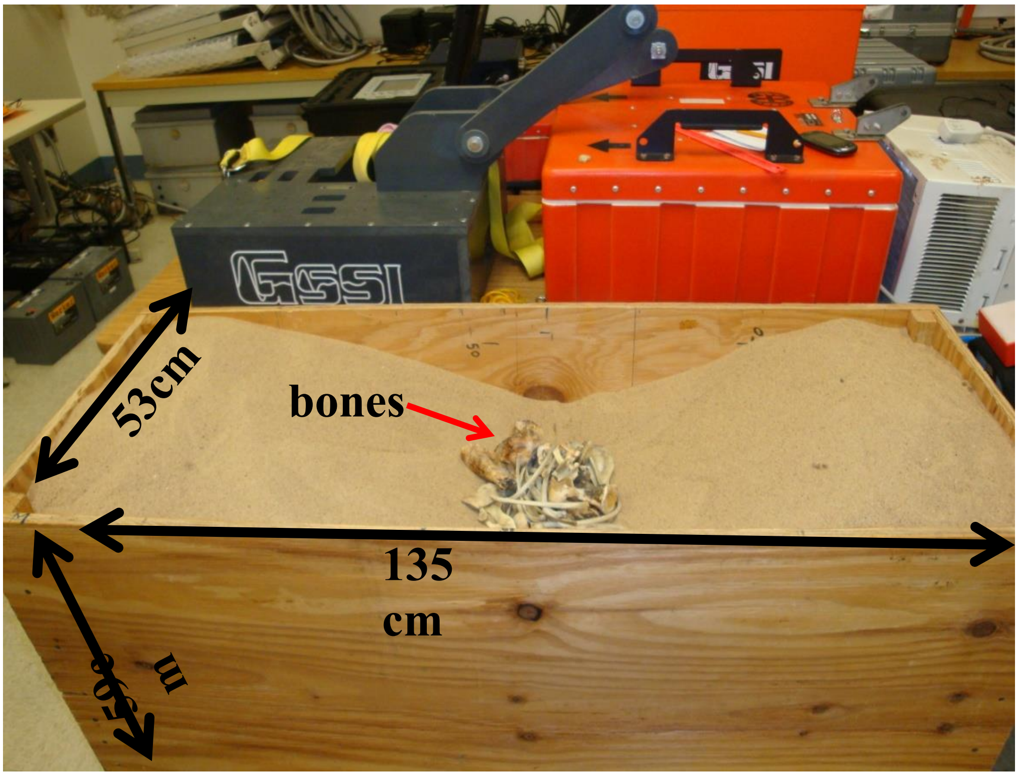

Figure 1: The laboratory wooden box with bones with its outside dimensions

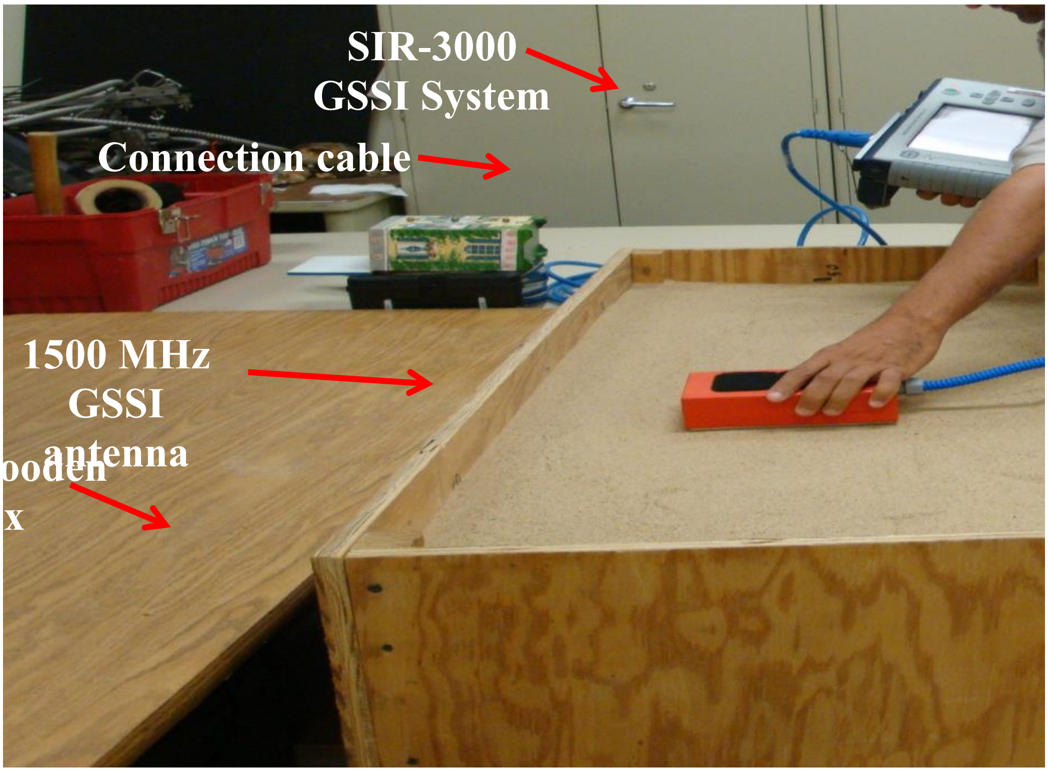

Figure 2: The GPR system used in the experiment GSSI-SIR-3000 with 1.5 GHz antenna

Figure 3: In situ dielectric constant measurements by Steven's Soil Sensor

Eight GPR profiles were conducted; three ran parallel to the box's long axis, four were perpendicular to the box's long axis, and the last ran parallel to the long axis with different antenna's polarization (Figure 4).

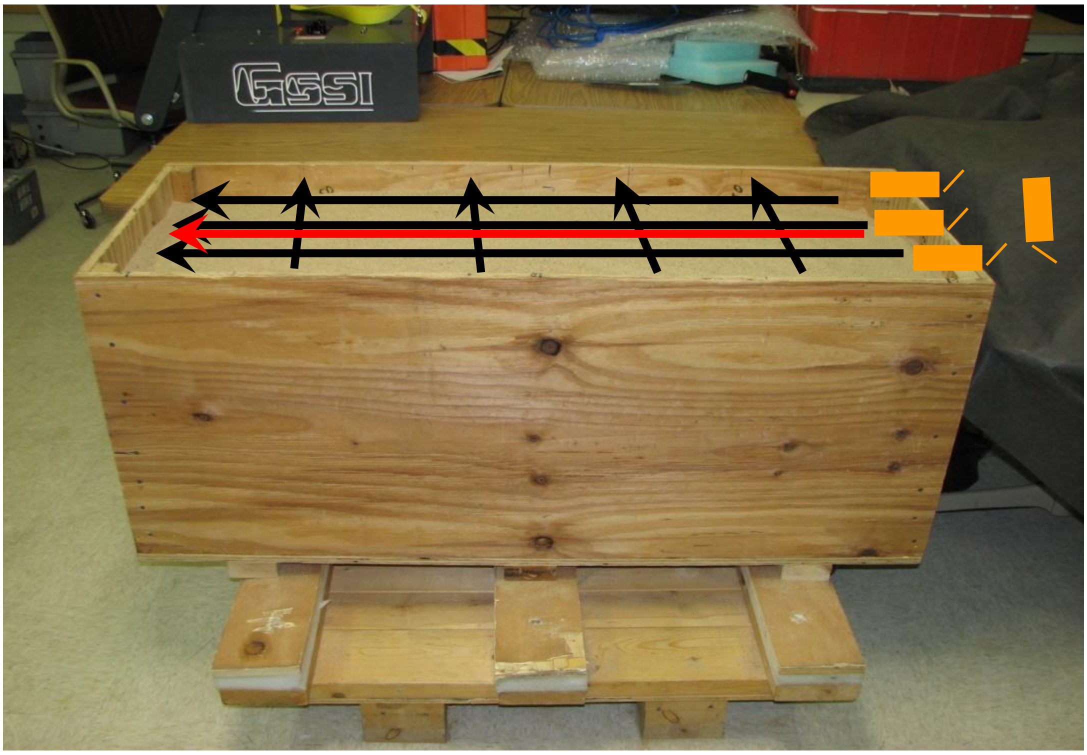

Figure 4: The survey design, the black lines are the same antenna's polarization as shown in orange rectangles, and the red line was with different antenna's polarization.

3. Data Processing

To modify the GPR row data, many data processing steps must be applied. These steps will make GPR row data with clear visualization and more accessible and accurate interpretation. RADAN 7 GSSI software was used to do post-processed steps [65]. Targets' accurate depths can be reached by applying the zero time process by adjusting the zero time with zero depth; therefore, any time offset should be removed before the interpretation (Figure 5).

Most GPR data contains noise and undesirable reflections; sometimes, this noise appears as horizontal reflections in the GPR data. The source of these noises is antenna's ringing. Also, a noise is generated due to the multiple reflections between the ground surface and the antenna. All noise can be deleted by applying the background removal process (Figure 5).

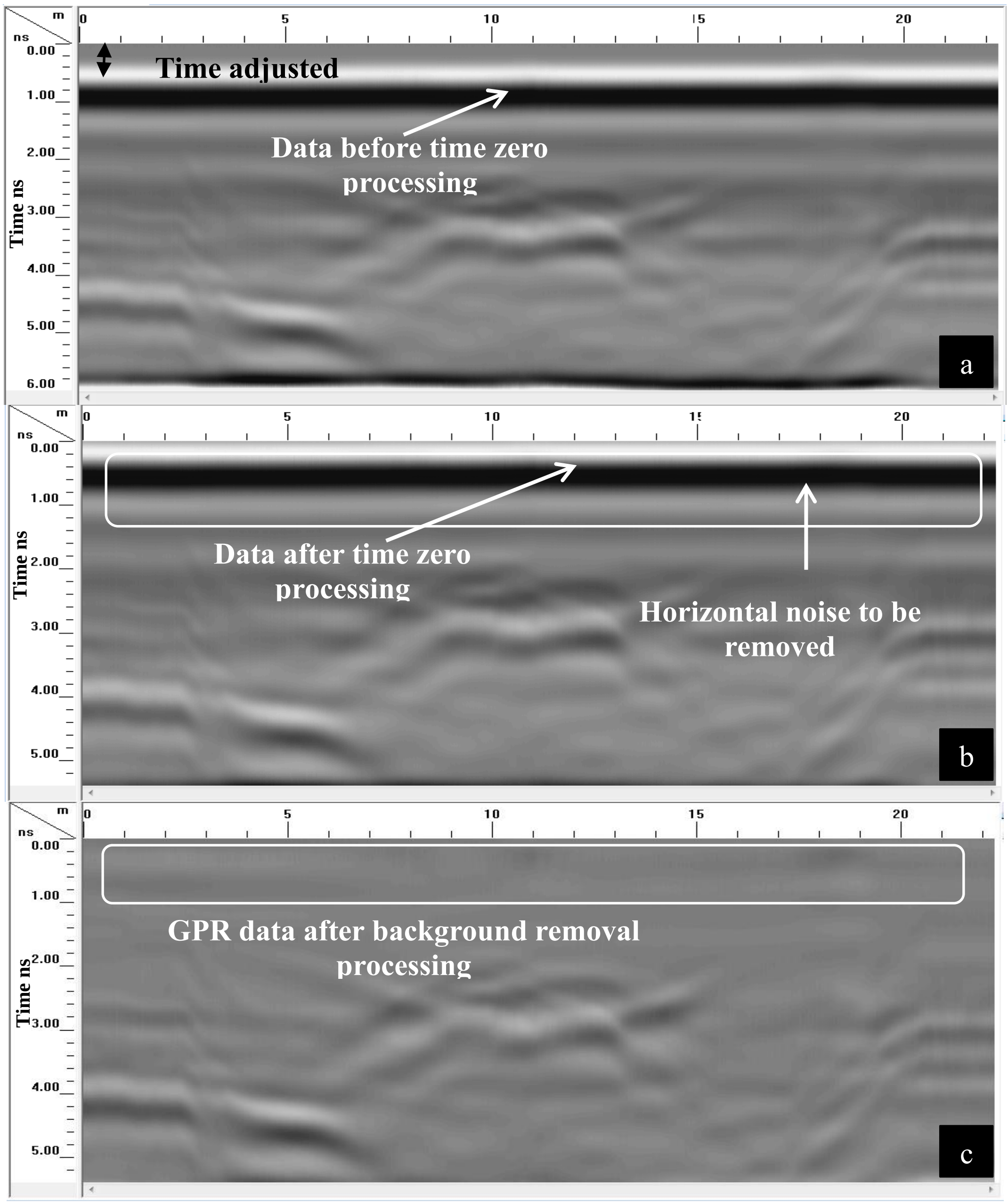

Figure 5: GPR data (1.5 GHz antenna) of the bones buried in the sand. a, before the time zero process, b, after the time zero process, c, after time zero and background removal process.

4. Results and Discussion

As a first step and for an understanding of the relationship between the antenna radiation pattern and the survey direction, two antenna configurations (polarizations) were examined. One is perpendicular to the box's long axis, while the other is parallel to the long axis (Figure 6). There was a clear difference in the reflection or the clarity of the "target" when changing the polarization. This is because the target size perpendicular to the box's long axis is larger than the parallel direction, and it is unrelated to other target long axes such as pipes or cables [63]; [64]. The human body will accumulate randomly so no long axis will be visible.

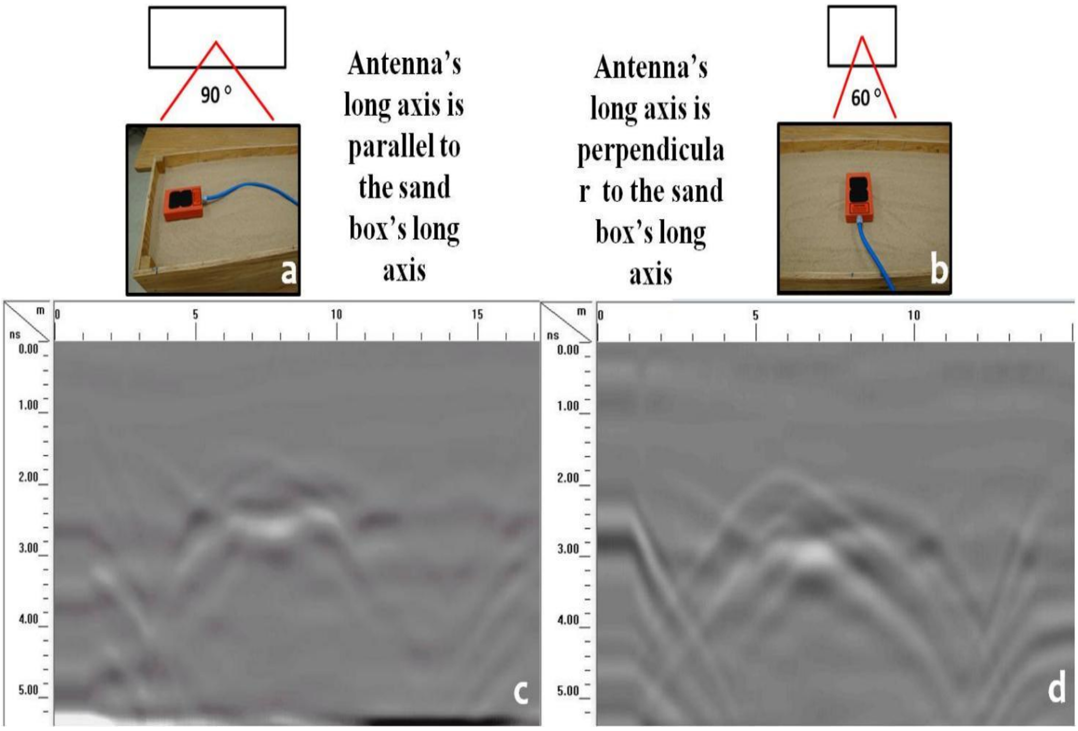

Figure 6: Antenna's radiation pattern (polarization). a, parallel to the box sand long axis, b, perpendicular on the long axis, the GPR profiles display belonged to the two polarization, c and d, respectively

All the GPR profiles are shown in Figure 7; these profiles have numbers (1-7) that belong to the profile survey's location on the experiment sandbox. As is clear by observing the profiles, profiles 1, 4 and 7 showed just the soil disturbance after burying the bones. Also, the sand was compacted by hand to make it stable while putting the bones, which simulates the mass graves after digging by machines such as bulldozers that will compact the soil due to the load of the machines; after that, the sand was added and covers the bones. Therefore, one can see these boundaries in the three profiles mentioned above in addition to the soil disturbance; these profiles were far from the bones on the close, left, and right sides of the box. The boundary between the sand and the buried bones is very clear in profiles 2 and 3. This is because these profiles ran exactly over the bones, so they conducted sharp oblique reflections on the left and right sides in the 2 and 3 GPR profiles. These are the edges of simulated mass graves that are very important in actual cases to start a correct procedure in mass graves recovery [7].

Simulated human remains (bones) appeared clearly in profiles 2, 3, 5, and 6 in the middle of profiles because the antenna was running directly over the buried bones, and due to the chemical and physical differences between the bones and the surrounding areas (sand) which will be reflected on their dielectric constant resulting different reflections that will come from the human remains. Profiles 4, 5, 6 and 7 did not reflect the boundary between the sand and the bones due to the short distance of these profiles.

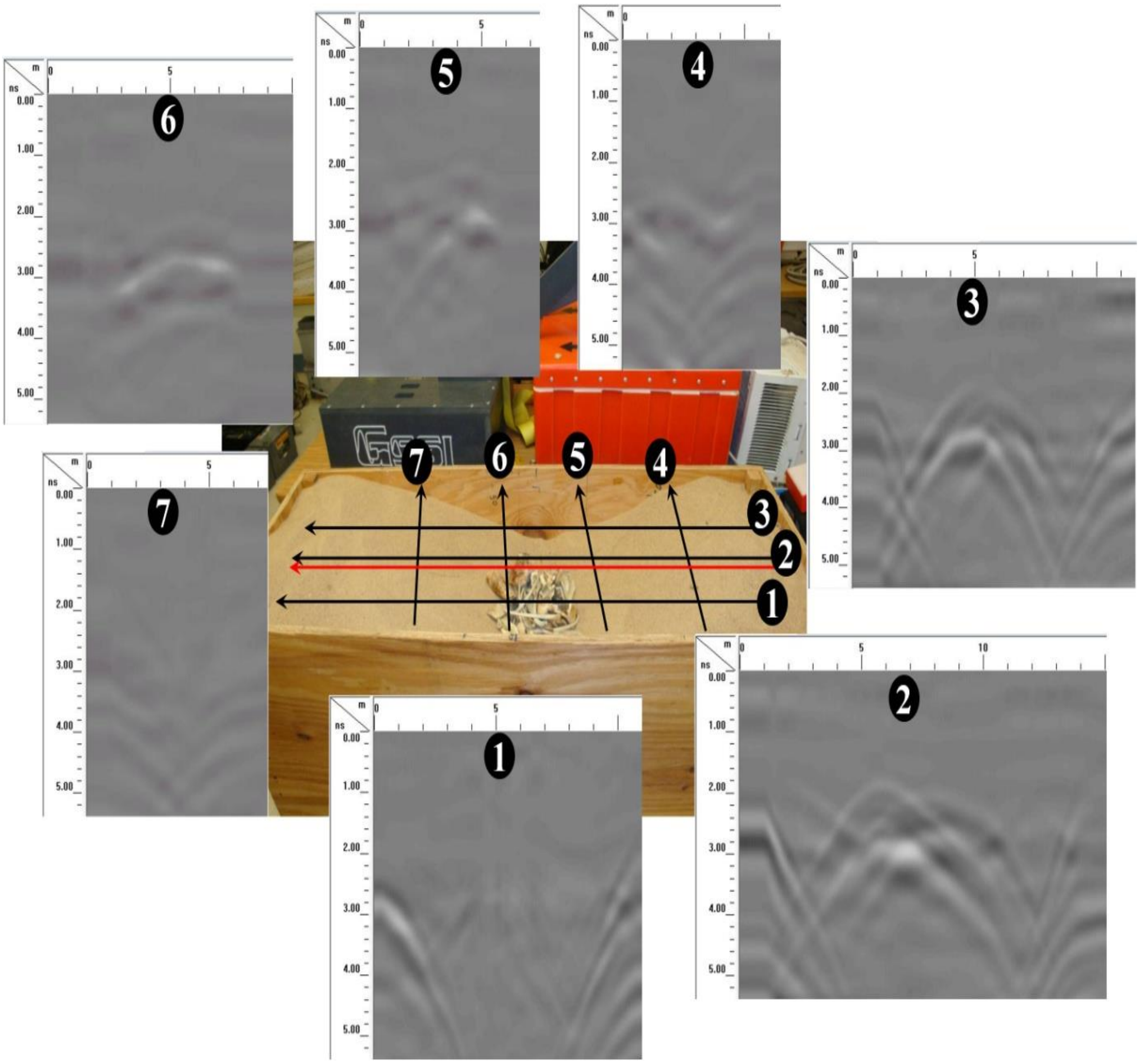

Figure 7: All GPR profiles and their location related to the experimental sandbox

The subsurface target's depth is significant to calculate. It can be calculated using equation (1) [32], when t which is the signal travel time (from the GPR profile) and $\mathcal{E}r$, which is the host medium's dielectric constant (from published tables or using devices such as Steven's Soil Sensor) are known. The two ways travel time is ≈ 1.8ns, and the sand-measured dielectric constant is 2.6. The calculated depth of the bones, *D*, was 0.167 m, as in equation (2):

$$D = \frac{c*t}{2\sqrt{\mathcal{E}r}} \quad (1)$$

Where (*D*) is the depth to the target, (*t*) is the travel time, (*c*) is the speed of light (0.3m/ns), ($\mathcal{E}r$) is the medium's dielectric constant.

$$D = \frac{0.3\frac{\text{m}}{\text{ns}}*1.8\text{ns}}{2\sqrt{2.6}} = 0.167\text{m} \quad (2)$$

In the 3D view of the simulated mass grave GPR profiles (Figure 8), the simulated human remains (bones) are remarked by the dashed red oval, and it is clear, and the reflection is different when compared with the surrounding areas.

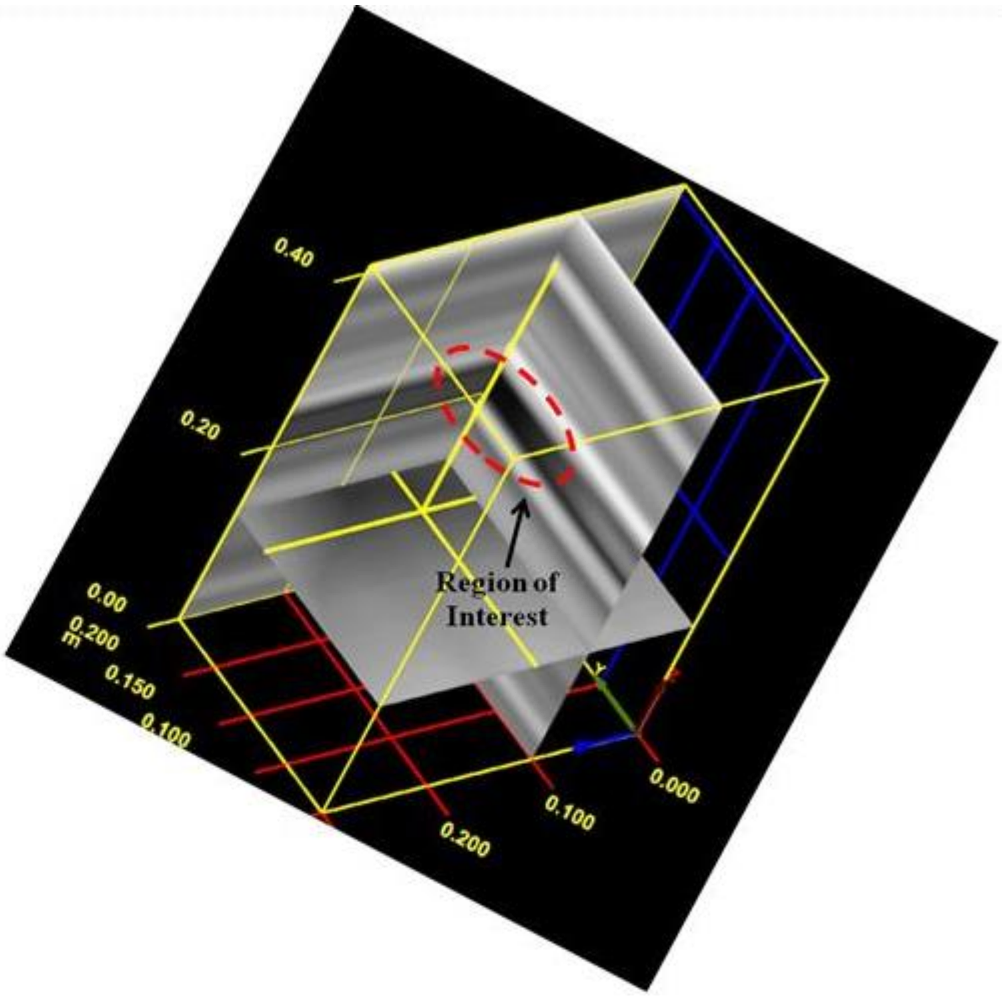

Figure 8: A 3D view of the simulated mass grave GPR profiles (1.5GHz antenna), a dashed red oval representing the buried bones.

5. Conclusions

This work uses a GSSI SIR-3000 GPR system with a 1.5 GHz antenna. The laboratory showed that the GPR is very effective in detecting subsurface mass graves. Also, this geophysical technique showed its assistance in tracking the delineation of the mass graves within the sandy soils (desert environment), so it easily located the boundary between the simulated human remains (bones) and the surrounding materials (sand) due to the differences in their dielectric constant as a result of the chemical and physical differences between the bones and the surrounding areas which will be converted to different reflections. Changing the antenna configurations (polarizations) in the GPR survey over the simulated target showed a clear difference in the reflection or the clarity of the "target". The calculated depth of the buried bones was very close to the actual depth. This novel application of the GPR will help in Iraqi mass grave investigation, recovery and excavation in desert environments.

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