FastTIMES

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Landmines: Detection and Demining

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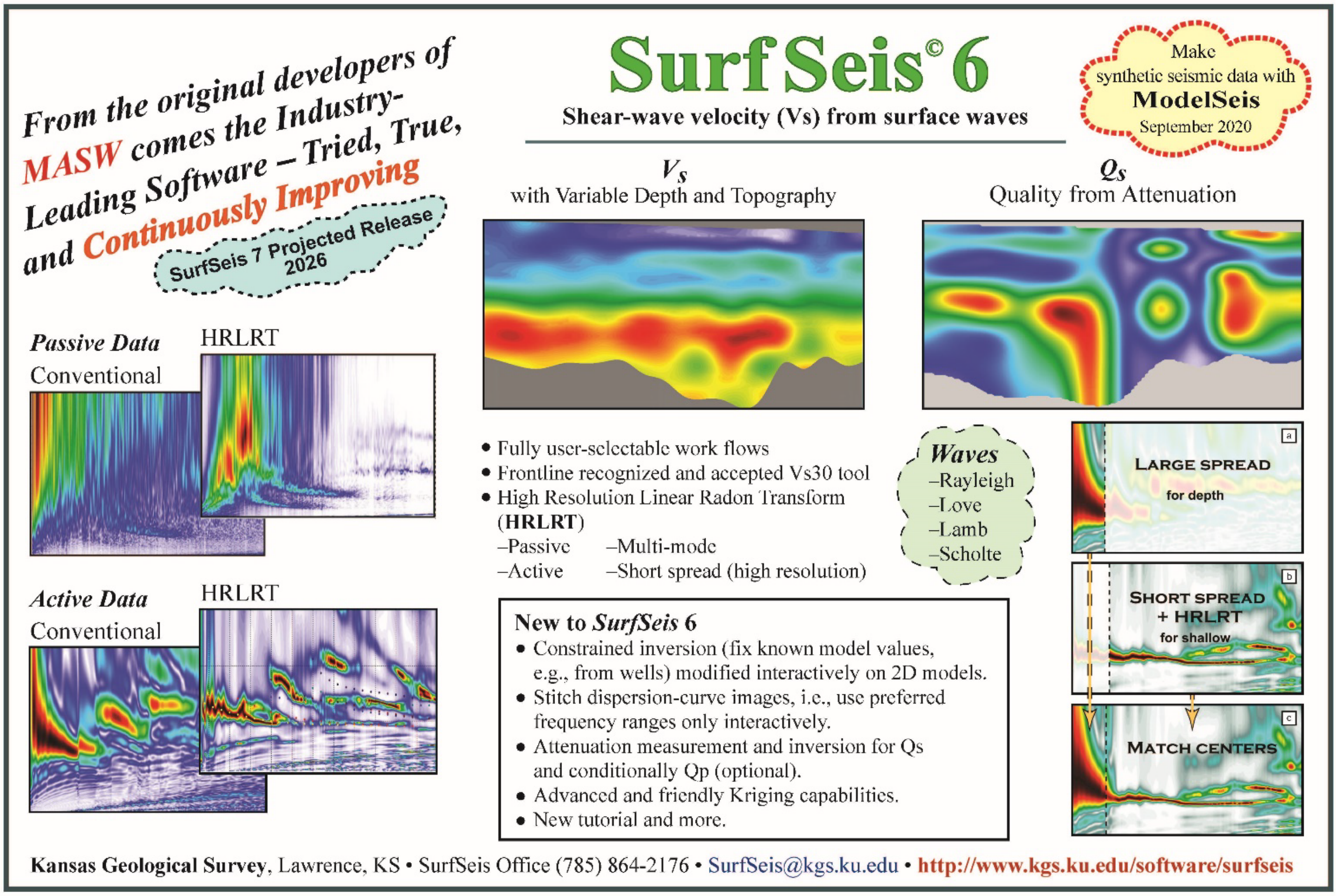

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The Conferences

SAGEEP is internationally recognized as the leading conference on the practical application of near surface geophysics. Since 1988, the symposium has featured nearly 300 oral and poster presentations, educational short courses and workshops, a commercial exhibition and field trips. This in-person SAGEEP once again brings together geoscientists from all over the world.

The Technical Program

The Technical Program typically features 300 oral and poster presentations. SAGEEP 2026 will be a source of the latest research and case studies. Fred Day-Lewis, VP SAGEEP, will be assembling his planning team who are are developing an impressive Technical Program, featuring several special sessions and invited speakers.

Host City - Pittsburgh

Pittsburgh is surrounded by hills and rivers and features scenic topography. The Monongahela, Allegheny and Ohio rivers come together in downtown Pittsburgh. Known as the "City of Bridges", Pittsburgh's over 446 bridges connect the city's various neighborhoods and provide stunning views of the skyline.

SAGEEP 2026's host city is home to notable institutions like the Carnegie Mellon University (CMU), University of Pittsburgh Medical Center, and the University of Pittsburgh. Pittsburgh attracts leading companies and research institutions in fields such as robotics, artificial intelligence, and advanced manufacturing. The city's commitment to innovation and entrepreneurship has positioned it as a global leader in cutting-edge technologies.

The Exhibits/Exhibitors

Over 10,000 square feet will be devoted to exhibitors bringing the latest in hardware, software, and services. Attendees will be watching for the EEGS Foundation Auction where valuable and sometimes historic items will be available for bids. Posters, a valuable component of the technical program, will be viewable in the Exhibit Hall.

Sponsor/Support Opportunities

Sponsoring the conference, a Special Session or a social event is an effective and economic way to increase visibility for your organization or services. SAGEEP meetings attract a targeted audience of geophysicists from multiple disciplines.

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President's Message

Environmental and Engineering Geophysical Society

Dale Rucker, President

Certerra Subsurface Imaging

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Over the past three decades working in environmental and engineering geophysics, I've seen the field evolve from relatively narrow, method-specific applications to a truly integrated science, that combines geophysics, geology, engineering, and data analytics to solve some of society's most urgent problems. Whether we're mapping groundwater resources, monitoring mines, assessing infrastructure, or detecting buried hazards, the goal remains the same: turn complex, often invisible subsurface conditions into usable information.

This issue of fastTIMES brings that mission into sharp focus. The articles on acoustic/seismic excitation for buried target detection, advanced magnetic and gravity methods, and dual-sensor humanitarian demining are great examples of how innovation and persistence drive our field forward. These aren't just technical successes. They are proof that when geophysicists tackle a problem, we do so with precision and a deep understanding of the physical world.

As someone who has spent years designing surveys for difficult environments, I'm reminded that the strength of geophysics lies not only in the tools we use but in our adaptability. Every site is different, and every dataset comes with its own quirks. Success comes from knowing when to apply the fundamentals, when to innovate, and when to push for new approaches entirely.

Looking ahead to SAGEEP 2026 in Pittsburgh, I see an opportunity for us to continue building that adaptability and cross-disciplinary thinking. Whether you're a researcher, a consultant, or a student, your work has the potential to address real-world needs in ways that only geophysics can. Let's make the upcoming conference a place where we connect our technical capabilities to societal benefits, share lessons, and inspire the next generation to take the field even further.

— Dale Rucker
President, EEGS

Editorial

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On behalf of the *FastTIMES* editorial team, I am honored to welcome you to Vol 27.3, dedicated to one of the most pressing humanitarian and environmental challenges of our time – Landmine Detection and Clearance. In this issue, we feature outstanding contributions from leading experts working at the intersection of geophysics, engineering, and humanitarian demining. With more than 60 countries still affected by landmines and other explosive remnants of war, the contributions featured here reflect not only geophysical progress but also the collective commitment to safeguarding communities, restoring land for safe, civilian use and rebuilding lives. This issue builds on our commitment to providing high-quality *FastTIMES* content that highlights the crucial role that geophysics can play in addressing complex, real-world problems with precision and impact.

I would like to extend my heartfelt thanks to our past EEGS president and guest editor, Janet Simms and Gad El-Qady, whose expertise and dedication have been instrumental in bringing together the valuable contributions in this outstanding issue. A special acknowledgment is due to Doug Crice (Geostuff) and Jackie Jacoby (EEGS administration) for their tireless efforts in communicating with our advertisers whose support is fundamental to the financial viability of *FastTIMES*.

I hope you find this issue both informative and inspiring. Enjoy your reading, and please take the time to explore the websites of our advertisers. Thank you for your ongoing support, and we look forward to your continued support and active participation in shaping the future of *FastTIMES*. As we move forward, I encourage all of you to engage with the articles and share your insights. *FastTIMES* is more than just a publication; together we can make it a platform for collaboration and innovation!

Sincerely,

Mehrez Elwaseif
Editor-in-Chief, *FastTIMES*

Application of Acoustic and Seismic Excitations for Characterization and Detection of Shallow Buried Targets

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Abstract

Acoustic and seismic ground excitation can be used to detect high-contrast, ultra-shallow buried objects such as landmines. Propagating acoustic or seismic waves interact with the buried object, exciting resonant oscillations that result in higher ground surface vibrations at the buried object's location. The object's resonances or excitation response can be used as an attribute for the detection of shallow buried objects. The response of an anti-tank mine, buried at multiple shallow depths, subject to acoustic and seismic ground excitation, is measured in the field. The study is conducted in soft (grass) and hard soil (limestone). In the meantime, 3D finite-element modeling in the frequency domain is performed to simulate seismic wave propagation, scattering, and excitation of the buried mine. Computer simulation results are used to correlate the field measurements on and off the buried target. Field measurements showed that, for both source types, the off-target vibration level is higher in the soft soil than in the hard soil. For both soil types, the seismic source generates higher on and off-target vibration levels due to the shaker's direct coupling compared to the speaker. However, the on/off object velocity contrast is greater for the loudspeaker. For both source and soil types, the target's resonant frequencies increase while the on/off velocity ratios decrease with increasing depth of burial. This depth-dependent behavior is attributed to the mass loading above the mine and the soil shear stiffness with burial depth. The 3D synthetic simulations showed good agreement with the field data. The simulation results also confirmed that the variations in the physical parameters of landmine, overburden (topsoil), native surrounding soil, and source type change the buried object's response to excitation.

Introduction

Acoustic detection of buried objects, such as mines, has proven itself as a technique that provides a high probability of detection and a very low false alarm rate. The method consists of exciting ground vibrations and measuring the vibration characteristics of the ground at many points with a non-contact vibration sensor, for example, a laser Doppler vibrometer (Aranchuk et al., 2006). The interaction of a buried object with the elastic waves in the ground causes the object to vibrate, resulting in a vibration anomaly at the ground surface above the object. This can have certain applications for the detection of buried high-contrast small objects such as landmines.

A buried mine is a coupled system where the mine influences the dynamic properties of the soil column above it as shown in the inset of Figure 1. The response of the buried mine is dependent on the elastic properties of the mine itself, the burial depth (which affects the weight of the soil column above the mine), and the soil properties of the disturbed soil column and the native soil (Donskoy, 1999) showed that soil shear stiffness is a key governing parameter determining the resonance vibration frequency and the amplitude of the soil-mine system. Soil moisture and consolidation increase soil shear stiffness, influencing modal vibrations of buried mines (Zagrai et al., 2005).

When soil is excited with acoustic or seismic waves, it vibrates at certain frequencies directly above the mine with a greater amplitude than the surrounding soil (Donskoy, Ekimov, Desunov, and Tsionskiy, 2002). It is postulated and well-documented that many man-made objects have unique vibrational responses as a function of frequency (Korman et al., 2004). These are associated with different vibrational modes within the structure and depend on the size and construction of the object (Scott and Martin, 1999). For many objects of interest, such as landmines, these unique structural characteristics allow their detection using acoustic and seismic excitations (Bakhtiari Rad and Hickey, 2021). The resonant frequency of a mine is determined by exciting the ground using a frequency sweep or band-limited noise and determining the frequency at which the largest vibration or on-off velocity response is obtained.

During the acoustic excitation (red lines in Figure 1), loudspeaker sources predominantly generate acoustic energy, propagating through the air and coupling locally into the ground. Since the acoustic propagation is within the air, the ground condition along the propagation path does not influence it, and the only dependence is on the acoustic to seismic coupling (Sabatier and Xiang, 2000). The coupling is local in space, and deformation at the ground surface is predominantly perpendicular to the surface. For outdoor ground surfaces, much of the acoustic energy can be reflected. Therefore, the efficiency of coupling acoustic energy into ground vibrations is a limiting factor in acoustic detection methods. Furthermore, the acoustic to seismic function depends on the mechanical properties of the ground and is therefore quite variable. A loudspeaker system is traditionally used in landmine detection because it allows the system to be a non-contact ground excitation. However, delivering adequate acoustic power to excite buried mines from a safe standoff distance is difficult (Haupt and Kenneth, 2005).

A mechanical shaker generates seismic energy (black line in Figure 1) from direct contact with the ground surface and acoustic energy (blue lines in Figure 1) associated with the shaker noise. For seismic sources, the direct contact between the source and the ground surface provides a better energy transfer into the ground. However, this coupling is frequency dependent, and on many surfaces, seismic sources work best for frequencies up to 100 Hz, which can be limiting for buried object detection. The energy propagates through the ground primarily as surface seismic waves for this type of excitation. Although the geometrical spreading of these waves is less than that of acoustic waves, their decay with range is usually greater due to the larger attenuation of seismic waves in soils. For buried object detection at short distances from the source, the ground deformation due to the acoustic and seismic energy cannot be easily separated. In landmine detection, the need to be covert and investigate deeper depths has led to the use and study of mechanical shakers for ground excitation.

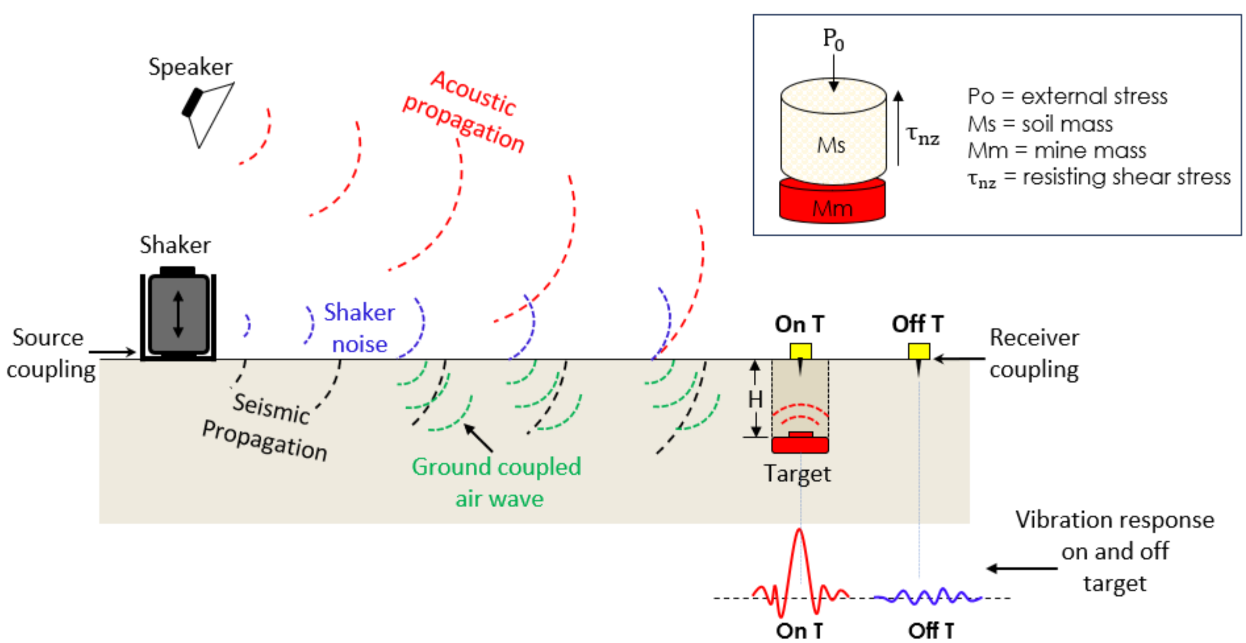

Figure 1. A schematic image showing the concept of landmine detection using seismic and acoustic excitation.

Field Data Measurements

An anti-tank, VS2.2 landmine simulant was chosen for characterization measurements. The VS2.2 simulant model shows a resonance frequency of about 101 Hz, measured in the lab (Figure 2). The resonance frequencies of the VS2.2 were measured using a Laser Doppler Vibrometer (LDV) (Aranchuk, Lal, Hess, & Sabatier, 2006).

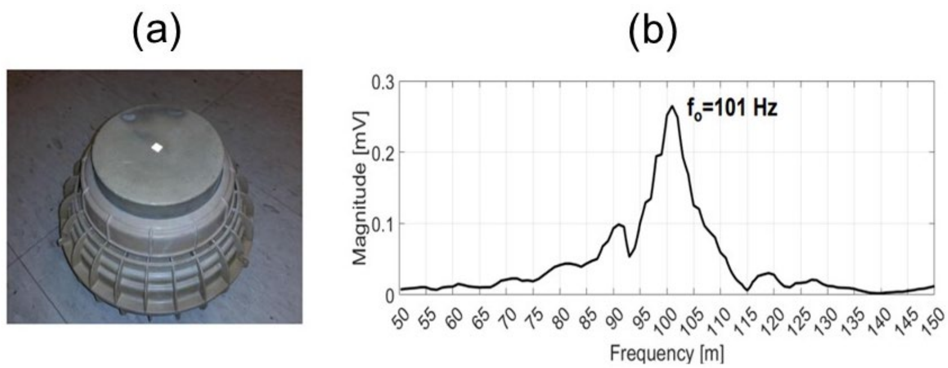

Figure 2. a) Anti-tank VS2.2 landmine simulant. b) The resonance frequency measurements of the VS2.2. Notice that the measurement is performed in the lab where the mine is isolated (not buried).

For field measurements, the mine was buried at two and six inches below the surface at a research location in Oxford, MS. Two survey sites were selected at the Oxford location. The first one, identified as a limestone site (gravel site), is a roadway constructed more than 15 years ago from a layer of crushed limestone above a silt loam representing hard soil (roadway). The second site is an undisturbed grass site with fine-grained silt soil, natural layering, and no vehicular traffic representing soft soil (off-road). The target characterization measurements were conducted using vertical accelerometers. Ceramic shear ICP accelerometers with a sensitivity of 1000 mV/g were used. Ground surface motion on and off the target was measured by placing an accelerometer at the center of the target and two accelerometers at 0.5m offset from the target (Figure 3).

The target was excited using acoustic and seismic excitation sources placed two meters from the buried target (Figure 3). The acoustic source is a JLB Professional speaker (model AWC15LF) with a 45 Hz to 2.2 kHz frequency range and a maximum SPL of 121 dB. The speaker was held at 1m above the ground during data collection, and a 5-second linear sweep input signal from 45 Hz to 180 Hz was used with an SPL level of 110 dB. The seismic source is a VTS mechanical shaker (model VG-100-6) with a DC–6.5 kHz frequency range and a peak force of 110 lbs. A similar input signal of a 5-second linear sweep from 45 Hz to 180 Hz was used for the shaker. To have comparable excitation energy with the speaker source, the output from the shaker was adjusted so that the vibration level at 1m offset was 0.5 µm/s.

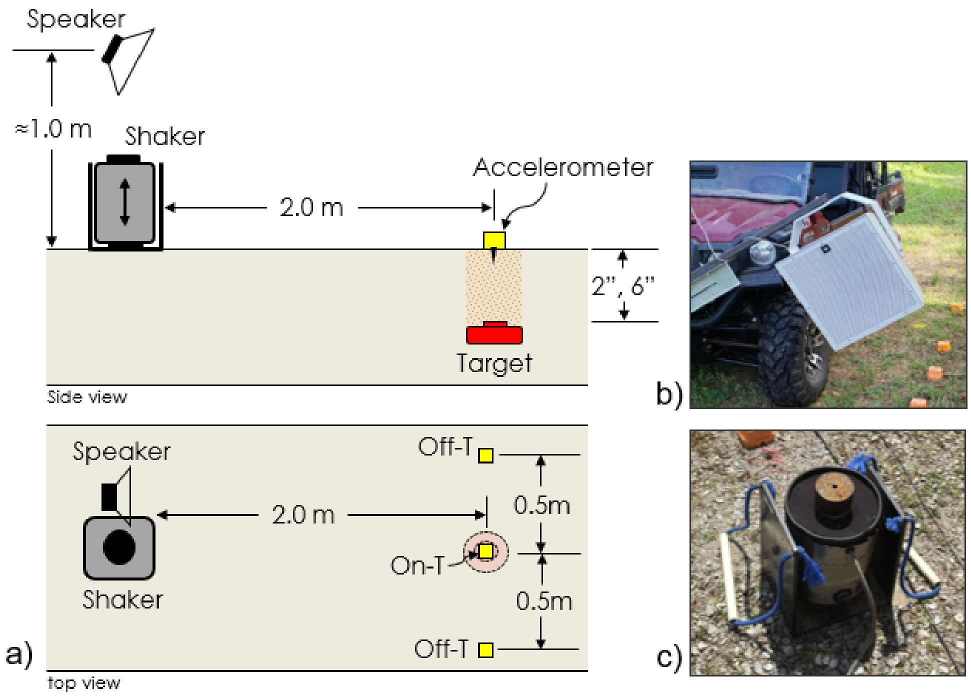

Figure 1. a) Field measurement geometry for landmine detection. b) The acoustic speaker used in the data collection. c) The seismic source (shaker).

3D Finite Element Simulations

Various 3D data simulations were performed to evaluate the mechanisms of landmine excitation and to correlate with the field-measured data. We have modeled a mechanical shaker and a speaker as sources in both the soft (grass site) and the hard (limestone site) media. The ground parameters required for simulation were estimated from geophysical surveys at both sites. For the limestone site, compressional wave speed V_P=355 m/s, shear wave speed V_S=210 m/s and density=1900 kg/m^3. For the grass site, compressional wave speed V_P=252 m/s, shear wave speed V_S=160 m/s, and density=1600 kg/m^3. The elastic parameters Young's modulus and Poisson's ratio were estimated using elastic relations. The source and sensor dimensions and offsets were chosen according to the field data measurements. The COMOSL software, a robust and efficient software for finite-element simulations, was used. The element size was comparable to the minimum wavelength to avoid numerical dispersion. The simulations were carried out in the frequency domain since it is fast, robust, and more efficient in controlling unwanted reflected waves coming off the boundaries.

The conceptual mine model representing the VS2.2 is shown in Figure 4a. Notice that this is a side view of the mine. The 3D mine is derived via rotation along its central axis. The mine comprises a main body and a thin lid. There is air between the main body and the lid, which is encompassed by a thin edge. The size and dimensions of the conceptual mine are the same as the actual mine simulant. What excites and resonates is the lid. The elastic parameters of the mine are chosen such that it produces the same resonant frequency (101 Hz) as the real mine simulant in the air (i.e., not buried). The COMSOL eigen-frequency package was used to calculate the resonance frequency of the isolated mine. The model was meshed using free tetrahedral elements for finite element modeling in the frequency domain. The mesh size was chosen to be finer in the top areas and coarser in the body areas, with minimum and maximum of 0.004 and 0.025 m (Figure 4b). The modeled lid is chosen to be Acrylic plastic with a density of 1300 kg/m^3, Young's modulus of 1e9, and Poisson's ratio of 0.36. The body of the modeled mine is a more rigid material with the density of 5000 kg/m^3, Young's modulus of 2e9 and Poisson's ratio of 0.25. The isotropic loss factor (η) is included in the modeling to represent the damping of the mine. Different trial values of 0.05, 0.1, and 0.2 were tested in order to produce the best fit to the frequency response curve of the real isolated mine. Tests revealed that the isotropic loss factor of 0.05 fits the real curve the best compared to other candidate values (Figure 4c). This FE-modeled mine produces the same resonance frequency as the real isolated mine (f_0=101 Hz).

Since often a hole is dug to bury the mine, a soft layer above the buried land mine needs to be used to represent the overburden soil. The overburden (topsoil) contributes to the excitation and needs to be included in the full simulation of the landmine response when it is buried. A landmine with overburden soil is a coupled system. The coupled overburden and mine need to be simulated together. The overburden layer is softer (less compact) than the native soil and has lower elastic parameters. Adding soil above the mine changes the mine response. Overburden geophysical parameters are different from the surrounding (native) soil. We considered 60% of the geophysical parameters (compressional and shear wave speed and density) of the native ground for topsoil. However, for the damping of the overburden, we used the same isotropic value as the native ground.

A full simulation of the landmine response when it is buried is shown in Figure 4(d). Since a hole was dug to bury the mine, a soft layer of soil was used as an overburden. Notice that the dimensions are exaggerated. The acoustic source was placed in the air at a height of 1m from the ground surface. The Monopole Point Source under the Transient Pressure Acoustics module in the COMSOL environment was used as an acoustic source. The monopole amplitude of the source was 20 N/m. The seismic source vertically vibrated the ground over a circular iron plate with a radius of 10cm. A free tetrahedron mesh model with a maximum size of 0.4m was used for maximum element size. The air density was 1.2 kg/m^3, and the sound speed was 343 m/s for modeling. The simulations were performed in the frequency domain. About 120 mono-frequency components ranging from 60Hz to 180Hz were simulated for both source types.

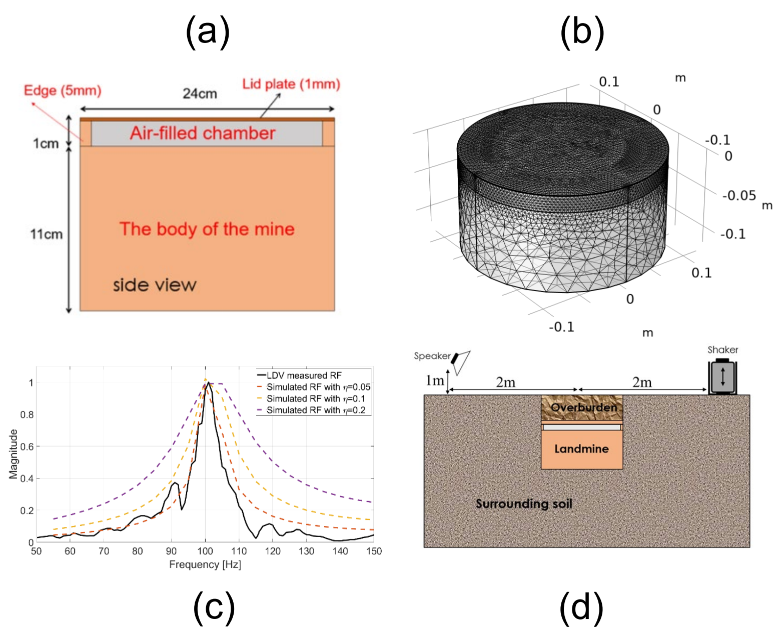

Figure 2. a) Side view of the conceptual VS2.2 mine model. Note that the 3D mine model is derived from the rotation of the 2D around its central axis. b) The 3D FE meshed model. c) Curve fitting to estimate the best loss factor (η) to determine the mine damping. d) Full simulation of landmine excitation using acoustic and seismic sources. Note that the dimensions are exaggerated in (d) for better visualization.

Data Results

Figure 5 to Figure 8 show the depth dependency with the speaker and shaker source in the limestone and grass sites. The solid lines represent the measured data results in all figures, and the dashed lines indicate the numerical simulations. Note that the vertical axis is the ratio of the vertical velocity (V_Z) of particle displacement on and off the mine.

Variation in depth

Figure 5 and Figure 6 show the depth dependency in the limestone site with the shaker and speaker source, respectively. The measured data with a shaker source on the limestone road (Figure 5) is noisy but shows a peak at about 122 Hz for the 2” buried mine and 160 Hz for the 6” buried mine. The synthetic data show good agreement with measured data for the shallow mine, but the agreement diminishes for the deeper mine. The response of the shallow mine using a speaker source (Figure 6) shows a peak at about 121 Hz and is significant and distinct compared to the shaker source. The measured and synthetic data with the speaker source agree well for the shallow mine. For the deeper mine, the data shows high noise levels, and the resonant peak at around 159 Hz is difficult to recognize. The synthetic data shows a peak at about 142 Hz for the deeper mine.

For the grass site, Figure 7 and Figure 8 show the depth dependency for a shaker and speaker source, respectively. The shaker source (Figure 7) shows a peak at about 106 Hz for the shallow buried mine. The synthetic data shows a good agreement with the field-measured data with a peak at 98Hz. However, the attenuation and velocity ratio do not agree with the measured values. For the deeper mine, the measured data shows a peak at 108 Hz, and the model shows a peak at 112 Hz. The measured data using a speaker source (Figure 8) shows a resonant frequency (peak) of 104 Hz for the shallow buried mine. It is hard to recognize a sharp peak for the deeper buried mine. The modeled data shows a good agreement in estimating resonant frequencies of shallow mine; however, attenuation is not well-estimated.

The results at both sites show that regardless of the source or soil type, with an increase in depth, ground vibration levels and on-target/off-target ratio decrease while resonant frequency increases.

Variations in source type

Analysis of the results shows that, for the same near-source offset, the seismic source generates higher on and off-target vibration levels for both soil types. However, the shaker source is anticipated to generate less vibration with increasing source offset due to the attenuation of the soil. For the limestone site, the velocity ratio with the speaker source (Figure 6) is about four times higher than the seismic source (Figure 5) at the same site. Similarly, for the grass site, the velocity ratio is higher for the grass site than that of the shaker source (Figure 7 versus Figure 8). This higher velocity ratio for the speaker source is due to the speaker's low off-target vibration level. Another observation is that in both soil types, similar resonant frequency values are observed from both sources.

Variations in soil type

The limestone site (hard soil) has higher on-target and lower off-target vibration levels. This leads to higher on-target/off-target ratios at resonant frequencies in the limestone soil.

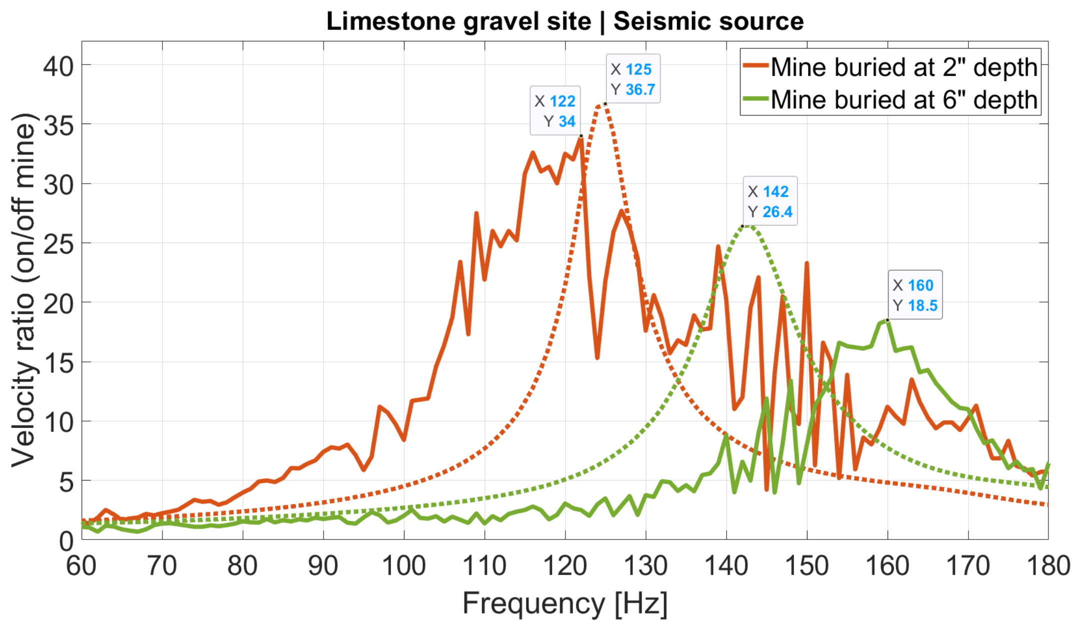

Figure 3. Depth dependency with the seismic source in the limestone site. Solid lines represent the measured data, and dotted lines indicate the simulations. Note that the vertical axis is the vertical velocity (V_Z) of particle displacement on and off the mine. Blue is the 2" buried mine, and green is the mine buried at 6".

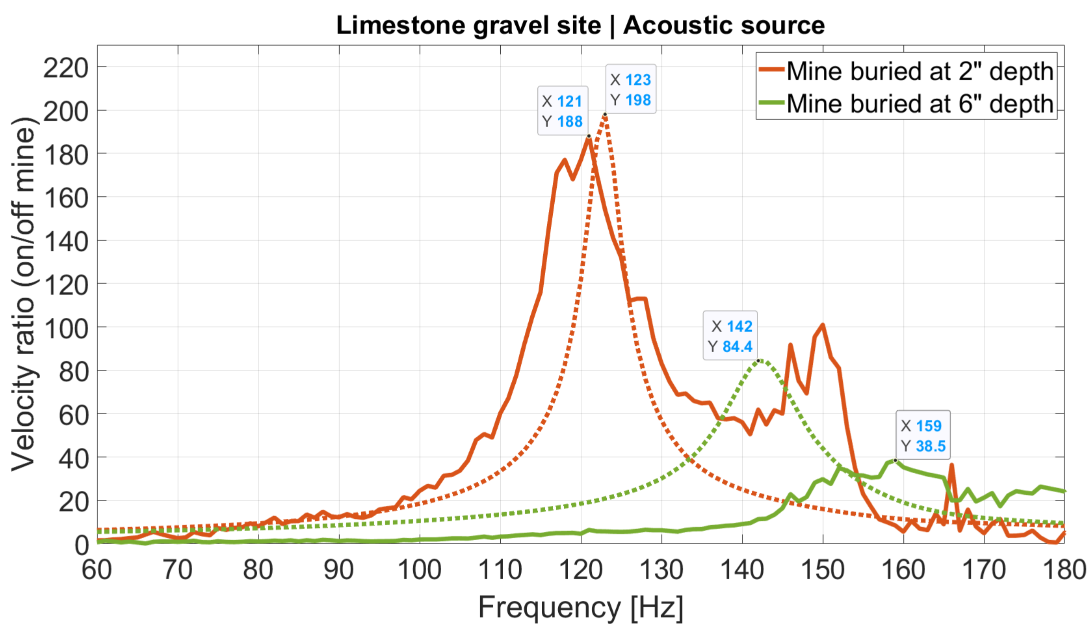

Figure 4. Depth dependency with the acoustic source in the limestone site. Solid lines represent the measured data and, dotted lines indicate the simulations. Note that the vertical axis is the vertical velocity (V_Z) of particle displacement on and off the mine. Blue is the 2" buried mine, and green is the mine buried at 6".

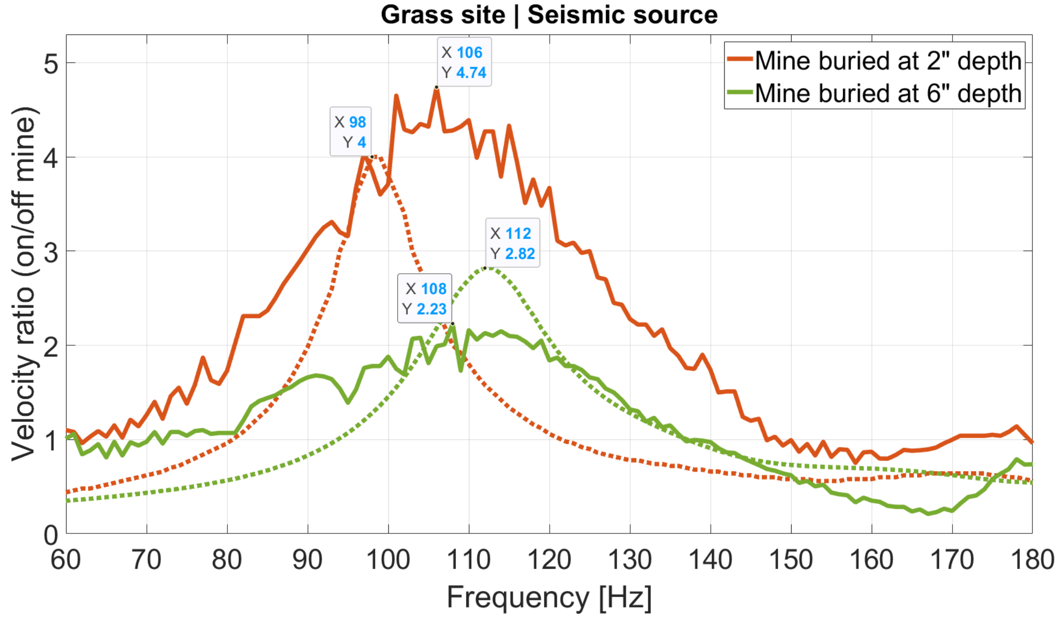

Figure 5. Depth dependency with the seismic source in the grass site. Solid lines represent the measured data, and dotted lines indicate the synthetic simulations. Note that the vertical axis is the vertical velocity (V_Z) of particle displacement on and off the mine. Blue is the 2" buried mine and green is the mine buried at 6".

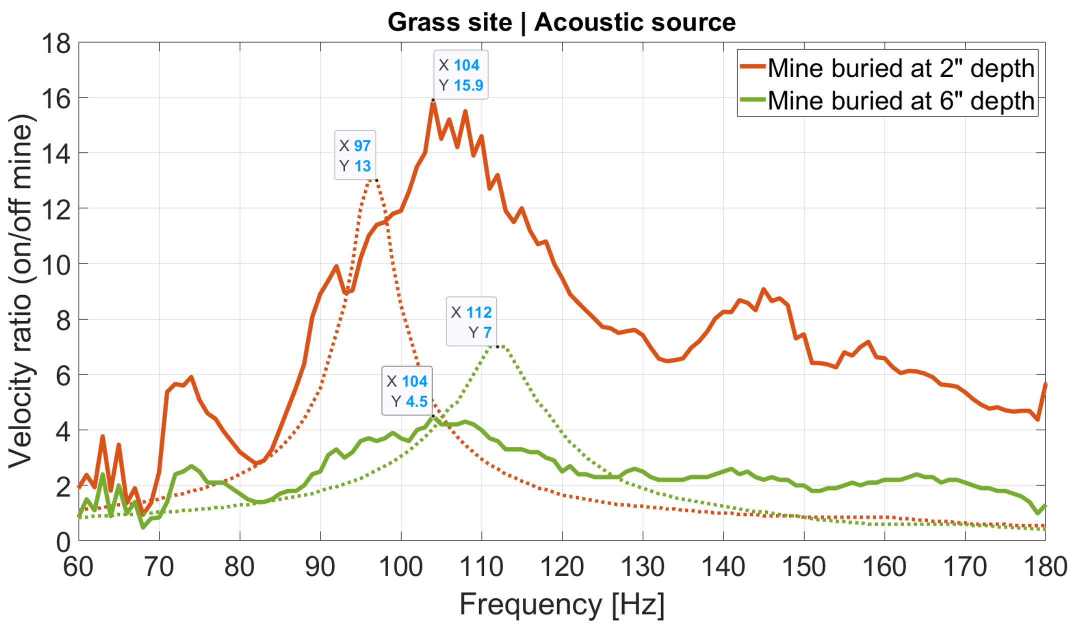

Figure 6: Depth dependency with the acoustic source in the grass site. Solid lines represent the measured data, and dotted lines indicate the simulations. Note that the vertical axis is the vertical velocity (V_Z) of particle displacement on and off the mine. Blue is the 2" buried mine, and green is the mine buried at 6".

Conclusions

Non-metal mines cannot be easily detected via electromagnetic methods. Thus, mechanical techniques are implemented to excite and detect such mines via their resonant frequencies. This research studies a non-metal landmine's response and resonance behavior when excited using seismic and acoustic sources. Field measurements and synthetic simulations were performed to evaluate the effect of various parameters in landmine detection. We have investigated the effect of the mine itself, the overburden, and the energy source. The conceptual overburden model is a less compacted version of the native soil and needs to be modeled. Field tests were performed in soft (grass site) and hard soil (limestone gravel) sites. 3D synthetic simulations were performed via the finite-element method in the frequency domain. For modeling, we introduced a conceptual mine model to represent the real mine model efficiently. A buried landmine shows different resonant frequencies than a mine isolated in the air. The simulations agreed with the measured data, particularly in estimating the resonant frequency. We showed that the overburden (topsoil), native surrounding soil, burial depth, and source type affect the mine's response. The acoustic source produces a higher on/off ratio than the shaker source. While the seismic source generates higher vibration levels at closer offsets, the acoustic source provides better contrast in the on/off ratio for landmine detection due to lower off-target vibration levels. Shallow-buried mines are easier to detect with distinct resonant frequencies compared to deeper-buried mines. Modeling the mine damping is still complex and needs further research.

Acknowledgement

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Author Bios

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Landmine Detection Using 3D Euler Deconvolution of Magnetic Data and Pseudogravity Transforms: Case Study of Osi NE, Central Nigeria

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Abstract

Landmines are a major problem in many areas of the world. In spite of the fact that many different types of landmine sensors have been developed, the detection of non-metallic landmines remains very difficult. The objective of this contribution is to employ the use of structural indices in the isolation of gemstones and other objects (e,g, landmines) from the ground using their structures or geometry. The isolation of landmine (military ordnances) and gemstones, based on structural identity, using the 3D Euler deconvolution of aeromagnetic and pseudogravity transforms have been employed in the mineral-rich zones of Osi NE (Sheet 225) area of central Nigeria. It was based on the analogy that both landmines and spherical host structures have the same structural index (SI), which can be used to isolate them before differentiating them with GPR techniques into ordnances or non-ordnances. The 3D structures, e.g. spheres and dipoles, that are commonly associated with certain gemstones have been successfully used to locate or identify landmines (tanks and drums) in certain parts of the world. The gravity and magnetic techniques proved to be fast and effective tool for detecting landmines, especially at regional scale; however, the differentiation and separation of the landmines from other non-ordnances involves the use of GPR techniques.

Introduction

Landmines are a type of inexpensive weapon widely used in the pre-conflicted areas in many countries worldwide. The two main types are the metallic and non-metallic (mostly plastic) landmines. They are most commonly investigated by magnetic, ground penetrating radar (GPR), and metal detector (MD) techniques. These geophysical techniques however have significant limitations in resolving the non-metallic landmines and wherever the host materials are conductive (Metwaly, 2007). Landmines are a major problem in many areas of the world. In spite of the fact that many different types of landmine sensors have been developed, the detection of non-metallic landmines remains very difficult. Most landmine detection sensors are affected by soil properties such as water content (Hong et al., 2001).

Reliable landmine detection is still an unresolved problem. Demining operations are complex activities because of the large variety of existing landmine types, many different possible soil and terrain conditions, and environmental circumstances. Because of its ability of detecting both metallic and non-metallic objects, ground penetrating radar (GPR) is a promising method for detecting landmines that may allow faster and safer operations. As the performance of GPR is mainly governed by the target signature, the potential of discriminating a target based on the presence of internal reflections could be a valuable advantage for the identification and recognition processes (Lombardi et al., 2018).

The gravity and magnetic (GM) techniques have been employed worldwide by geoscientists to explore for oil and solid minerals which abound in the subsurface structures of the earth. The use of Euler Deconvolution as an interpretation tool to determine source location of potential field anomalies is well established

(Mushayandebvu et al., 2004). Other methods for structural study include: 2D Forward modeling and inversion (Talwani and Heirtzler, 1964) and the estimation of the structural index (Barbosa et al., 1999) amongst others.

The use of the aeromagnetic and gravity method in this case is intended to focus additional exploration efforts in demining of pre-conflicted and war-torn areas by isolating buried landmines from the ground. The identification of the potential structure with 3D shape, like landmines (Figure 1) and gemstones, with the intent of isolating them from the ground is the goal of this research. The 3D structures (gemstones and/or landmines) are then differentiated and separated using internal structure detection from ground penetrating radar images.

Figure 1. A typical VS-50 landmine (after Lombardi et al., 2018).

Location, Geomorphology and Regional Geology

The study area covers Osi NE (Sheet 225) in the transition environment of Bida Basin and the Southwestern Nigerian Basement Complex (Figure 2). A Sheet comprises a ½ degree by ½ degree contour map on a scale of 1:100,000. The study area is bounded by latitudes 8° 15' and 8° 30' N and longitude 5°45' and 6° 00' E (Osi NE, Sheet 225) with an area extent of approximately 729 km^2 in the Bida basin area of central Nigeria. The vegetation is of the Guinea savannah type with two distinct seasons (rainy and dry) (Udo, 1982) with tropical Guinea type climate (Kehinde and Leohnert, 1989).

The Bida Basin is a NW-SE trending embayment perpendicular to the main axis of the Benue Trough and the Niger Delta Basin of Nigeria. The thin sedimentary cover overlying the basement rock in this transition environment is said to be responsible for the low depth to sources along magnetic profiles (Megwara and Udensi, 2014).

Materials and Methods

Data source and analysis

The aeromagnetic data of Osi NE (Sheet 225) was procured from the Nigeria Geological Survey Agency (NGSA), Abuja, Nigeria. The survey, which was aimed at mineral and ground water development, was collected at a flight height of 80 m, flight line spacing of 500 m, and tie line spacing of 2,000 m. The flight line direction was NW – SE, whereas the tie lines were NE - SW. For ease of processing, the data were stripped of a common value of 32,000 nT. Data collection for this area was done in 2006, so a 2005 epoch International Geomagnetic Reference Field (IGRF) was used to calculate inclination and declination as follows:

Field Strength = 33129.9632 nT;
Inclination = -6.87339275;
Declination = -2.51357917.

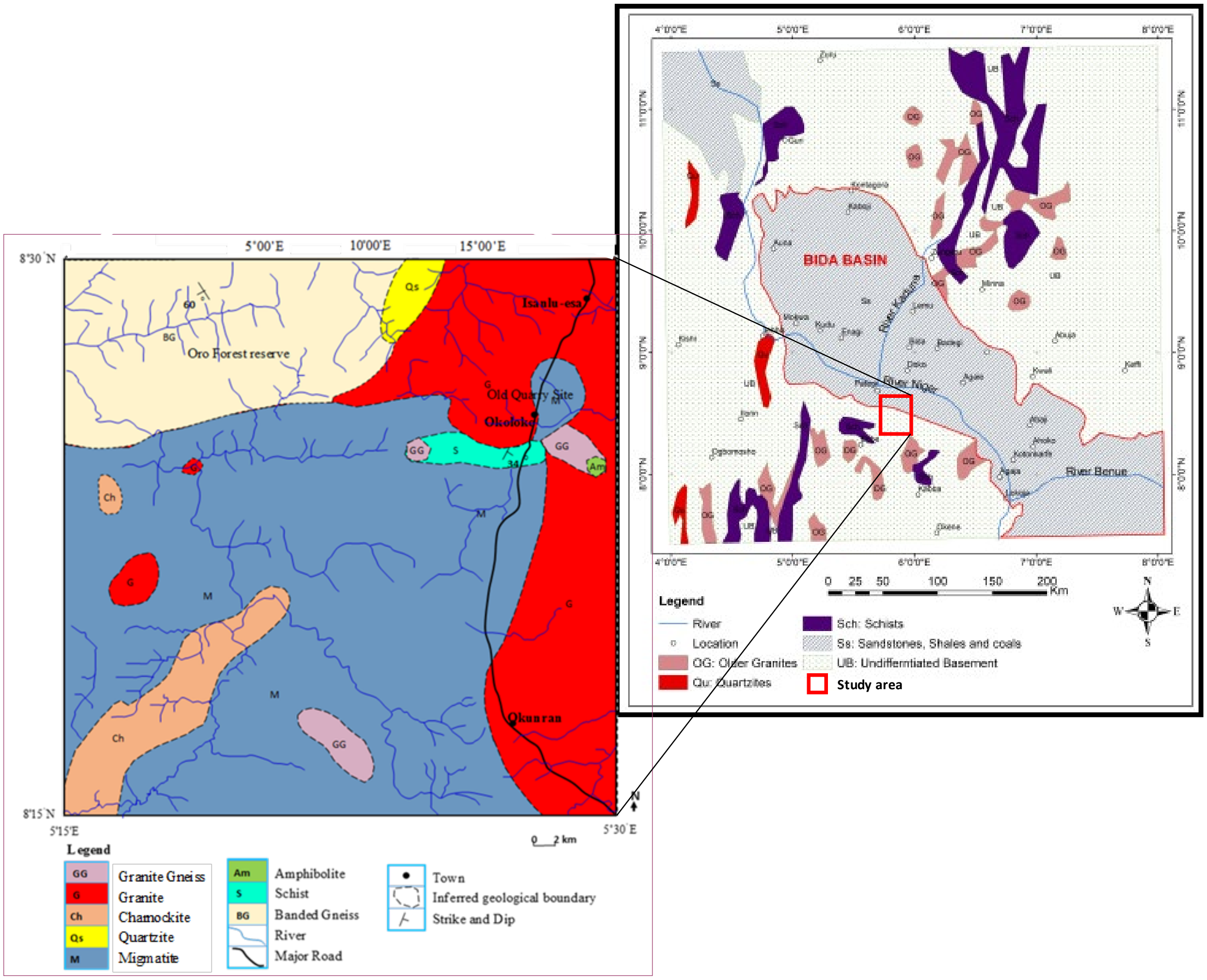

Figure 2. Geological map of the Osi NE study area as obtained from fieldwork. (Inset is the geological map of Bida basin; Adapted from Obaje et al., 2011).

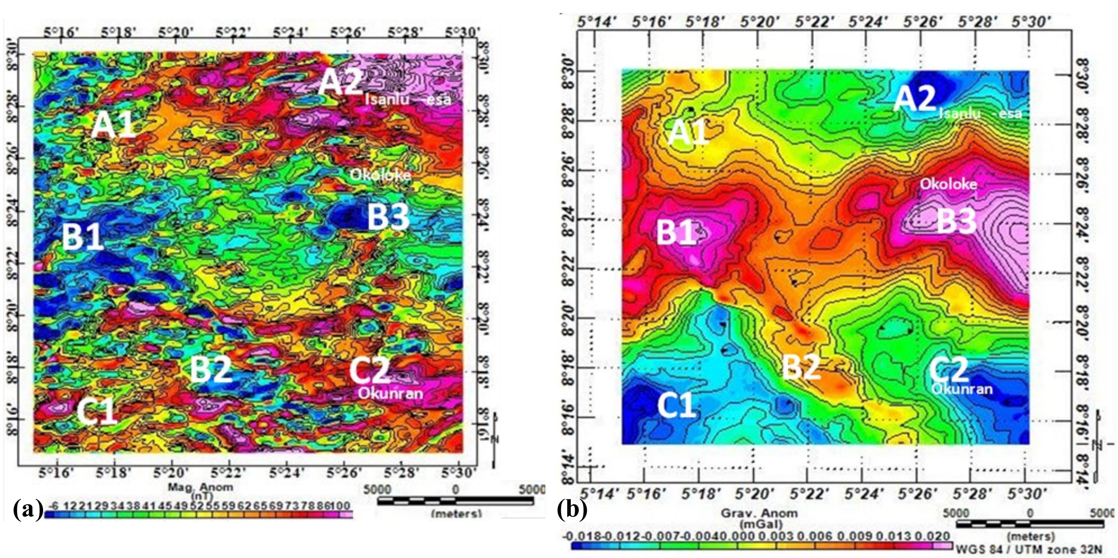

Figure 3. a) Total magnetic intensity map of the study area (REDE and its contour) (after NGSA, 2009). b) Pseudogravity transforms and its contour map.

Figures 3a and b are the Total Magnetic Intensity (TMI) reduced to the equator and pseudogravity transform maps of the study area, respectively. The maps emphasize the intensities and the wavelengths of the local anomalies that reveal information on the geometry, strike, contacts between rocks and intensities of magnetization and gravimetric values within the study area.

The 3D Euler Deconvolution Method

The 3D Euler deconvolution technique is an equivalent method based on the Euler's homogeneity equation as developed by Reid et al. (1990) following Thompson's (1973) suggestion and operating on gridded magnetic data. The equation relates the magnetic field and its gradient components to the location of the source, with the degrees of homogeneity n, which may be interpreted as a structural index (Thompson, 1982). The structural index (SI) is a measure of the rate of change with distance of the field (Whitehead and Musselman, 2005). The SI of 0.0, 2.0 and 3.0 (magnetic) and 0.0, 1.0 and 2.0 (gravity) represent step, pipe, and sphere, respectively. The correct SI for a given feature is that which gives the tightest clustering of solutions.

The 3-D Euler deconvolution processing routine in Oasis Montaj™ is an automatic location and depth determination software package for gridded magnetic and gravity data. The Euler derived interpretation requires only a little a priori knowledge about the magnetic source geometry and information about the magnetization vector (Barbosa et al., 2000).

Theory of Euler deconvolution method

Any three-dimensional function $f(x,y,z)$ is said to be homogeneous of degree n if the function obeys the expression (Whitehead and Musselman, 2005):

$$f(tx, ty, tz) = t^n \, f(x, y, z) \qquad (1)$$

From this it can be shown that the following (known as *Euler's equation*) is also satisfied (Whitehead and Musselman, 2005):

From this it can be shown that the following (known as *Euler's equation*) is also satisfied (Whitehead and Musselman, 2005):

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial f}{\partial z} = nf \qquad (2)$$

Thompson (1982) has shown that simple magnetic and gravity models conform to Euler's equation. The degree of homogeneity, n, can be interpreted as a structural index (SI). Reid et al. (1990) have shown that a magnetic contact will yield an index of 0.5 provided that an offset A is introduced to incorporate an anomaly amplitude, strike and dip factors (Whitehead and Musselman, 2005):

$$A = (x \quad x_0)\frac{\partial T}{\partial x} + (y \quad y_0)\frac{\partial T}{\partial y} + (z \quad z_0)\frac{\partial T}{\partial z} \qquad (3)$$

Given a set of observed total field data, we can determine an optimum source location (x_0, y_0, z_0) by solving Euler's equations for a given index n by least-squares inversion of the data.

Results and Discussion

Pattern interpretation of the aeromagnetic and gravity data

Figure 3a is the TMI map and its contour that has been reduced to the equator using the REDE submenu of Oasis montaj™ software, while Figure 3b is the pseudogravity map and its contour. For qualitative analysis, the aeromagnetic and pseudogravity anomaly maps have been divided into three distinct zones and subzones of various magnetic and gravimetric characteristics based on their patterns. These include:

(i) Zone A is characterized by anomalies with moderately high to very high magnetic reliefs (i.e. A1 and A2; Figure 3a) with corresponding low to very low density reliefs (i.e. A1 and A2; Figure 3b) in the Northern part of the study area. The amplitudes here vary mostly from < 52 to > 100 nT and from < -0.018 mGal to approx. 0.003 mGal for magnetic data and pseudogravity transforms, respectively. The major rocks here include banded gneiss, quartzite and granite.

(ii) Zone B is characterized by low to intermediate magnetic reliefs (i.e. subzones B1`to B3; Figure

3a) with corresponding high density reliefs (i.e. subzones B1 to B3; Figure 3b) in the central part of the study area. The anomalies in this zone have amplitudes varying mostly from < -6 nT to 52 nT and 0.003 to approx. 0.025 mGal for magnetic data and pseudogravity transforms, respectively. The rocks here include migmatite, granite, schist, granite gneiss and charnockite.

(iii) Zone C is characterized by a mixture of high and moderately low magnetic reliefs (i.e. subzones C1 and C2; Figure 3a) with corresponding moderate and low pseudogravity reliefs (i.e. subzones C1 and C2; Figure 3b). These anomalies have amplitudes of approx. 29 to > 100 nT and -0.018 to approx. 0.001 mGal for the magnetic and gravity data, respectively. This zone is associated on the geological map with charnockite, granite and migmatite.

Zone coloured Euler solutions for 3D structures

Figure 4a shows the results obtained for structural index 3.0 (i.e. sphere or dipole model; magnetic). The zones where there are several clusters are labelled A to F for spheres or dipoles. In Oasis montaj™, window size determination is either by default (i.e. 20 x 20) or through iterations, as the correct SI for a given feature will give the tightest clustering of solutions or sharpest focus of results. Tanks and drums have been detected or explored worldwide with structural index 3.0 (magnetic) of 3D Euler deconvolution (Marchetti and Settimi, 2011). Figure 4b is the geologic map of the study area showing the different zones and the corresponding lithologies with the magnetic structures.

From Figures 4a and b, which represent the magnetic 3D structures obtained from 3D Euler deconvolution and their corresponding rock types, it is clear that zone A (banded gneiss, migmatite and granite), B (granite, migmatite, granite gneiss, schist and amphibolite), C (migmatite), D (migmatite, granite, charnockite and granite gneiss), E (migmatite, granite gneiss) and F (granite) are the corresponding rock types for the different zones.

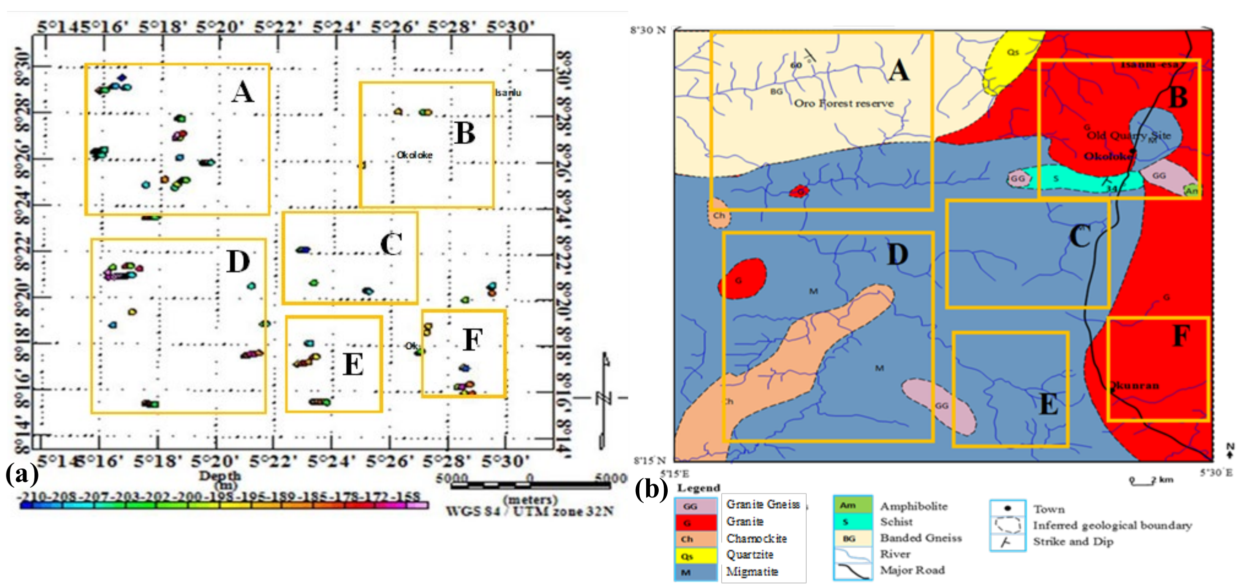

Figure 4. a) A typical aeromagnetic Euler solutions map for sphere (S.I =3.0) showing the zones of clustering. b) Geological map of the study area showing the different zones where spheres (aeromagnetic) cluster and their corresponding rock types.

Figure 5a shows the result obtained for structural index 2.0 (i.e. sphere or dipole model; pseudogravity). The areas where there are several clusters are labelled G to J for sphere. Tanks and drums have been detected or explored worldwide with structural index 2.0 (gravity) of 3D Euler deconvolution (Marchetti and Settimi, 2011). Figure 5b is the geologic map of the study area showing the different zones and the corresponding lithologies with the gravimetric structures.

From Figures 5a and b, which represent the pseudogravity 3D structures obtained from 3D Euler deconvolution and their corresponding rock types, respectively, it is clear that zone G (banded gneiss), H (banded gneiss, quartzite and granite), I (migmatite, charnockite, granite and granite gneiss) and J (migmatite and granite) are the corresponding rock types for the different zones. Many of these spherical features are found all over the area, confirming that the area is very rich in mineral resources.

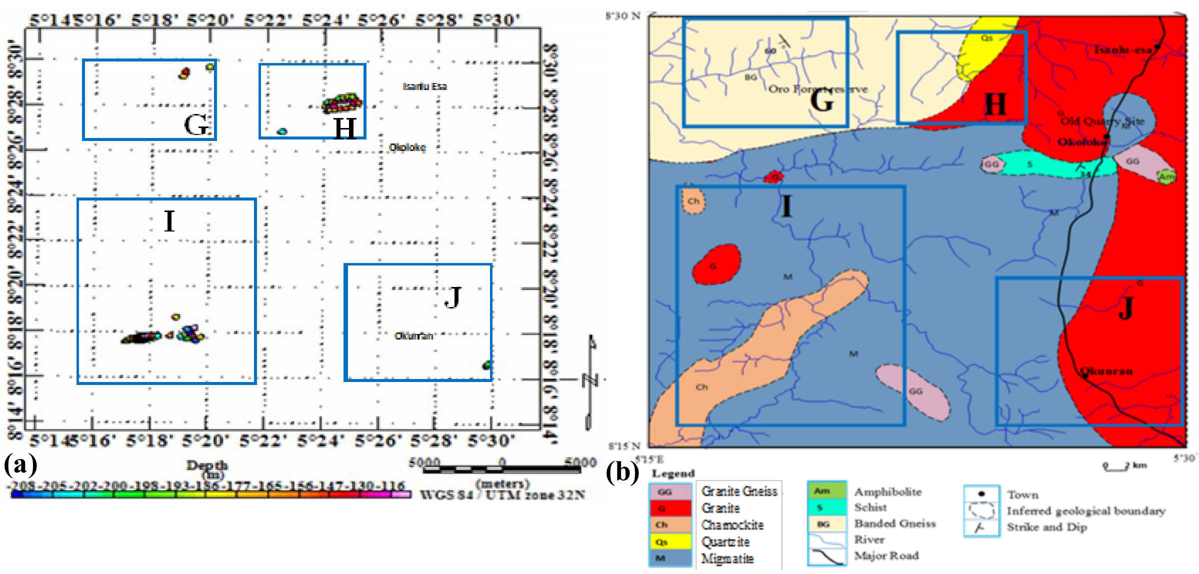

Figure 5. a) A typical pseudogravity Euler solutions map for sphere (S.I =2.0) showing the zones of clustering. b) Geological map of the study area showing the different zones where spheres (pseudogravity) cluster and their corresponding rock types.

Conclusions

Regional aeromagnetic data from Osi NE study area was processed for structural mapping and demining study. The different structures were delineated and especially the 3D structures which are represented by Euler structural indices 3.0 (i.e. sphere or dipole model; magnetic) and 2.0 (i.e. sphere or dipole model; pseudogravity) were first isolated using the 3D Euler deconvolution method in the study area. These 3D structures were then differentiated and separated into gemstones and/or landmines using internal structure detection technique from ground penetrating radar images. The abundance of spherical features in the study area confirms the usefulness of the 3D Euler in isolating spheres/dipoles or landmines and prospective zones for mineral exploration. The structural indices of 3.0 and 2.0 (i.e. sphere or dipole model) in magnetic and gravity, respectively, have been used worldwide to detect tanks and drums (or metalliferous bodies and landmines) (Yaghoobian et al., 1992; Marchetti and Settimi, 2011).

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Humanitarian Demining in Ukraine

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Abstract

New technologies are required for humanitarian demining for acceleration of landmine clearance activities. Dual sensor is a combination of electromagnetic induction sensor and ground penetrating radar (GPR), developed for landmine detection. Tohoku University, Japan has developed a dual sensor that can visualize the buried objects on a smartphone. This sensor uses 3-D migration algorithm for image reconstruction of GPR, which is useful for clutter reduction. In this article, we introduce the technology of this sensor and demonstrate its usefulness in the mine affected countries including Ukraine.

Introduction

Three years have passed since the outbreak of the war in Ukraine, and there are reports of damage caused by landmines left behind after the Russian military withdrew (Human rights watch, 2023). Since the 1990s, humanitarian demining activities have been carried out in post-conflict landmine-affected countries such as Cambodia and the former Yugoslavia countries. Geophysical exploration techniques such as magnetic exploration, electromagnetic exploration, and ground penetrating radar (GPR) are used to detect landmines and UXOs. We have developed a landmine detection sensor for humanitarian demining, ALIS: Advanced Landmine Imaging System, and have used it in landmine clearance activities in nine affected countries (Sato, 2025).

The Japanese prime minister Kishida visited Kiev in March 2023, and reiterated Japan's support in the field of humanitarian demining. Delivering ALIS is one of the supports by the Japanese government. Japan International Cooperation Agency (JICA) started a project to introduce ALIS for demining in Cambodia in 2022, and started a project for Ukraine (JICA 2023). This report describes a technical advantage of ALIS, and then we will introduce the use of ALIS in landmine-affected countries including Ukraine.

Humanitarian Demining

Landmine clearance activity is classified into two categories, namely military and humanitarian, and their purposes are very different. In military landmine detection, the purpose is to identify minefields and remove mines that obstruct the passage of vehicles, etc., and the probability of detecting landmines does not need to be 100%, but speed of work is pursued. Humanitarian demining, on the other hand, aims to ensure the safety of civilians living in the area by removing landmines after the conflict that caused the landmine problems has ended. In landmine-affected countries, there is a lot of landmine removal activity in farmlands, pastures, and forests, and the ultimate goal is to restore agricultural activity and revitalize economic activity by returning farmland and cultivated land to local farmers. Therefore, humanitarian demining is essentially meaningless unless 100% detection and removal is achieved, and the time that it takes to do so is overwhelmingly longer than military demining.

United Nations (UN) regulations for humanitarian demining require the removal of all metal objects up to 13 cm from the ground surface. However, in post-battle areas, many metal fragments such as bullets and bomb fragments are buried in the soil, making it difficult to detect and remove all metal fragments and landmines. It is therefore desirable to reduce work time through efficient geophysical exploration.

Geophysical Exploration Technologies Used for Landmine Detection

The targets of humanitarian demining include unexploded ordnance, cluster munitions, anti-tank mines, and anti-personnel land mines. Geophysical exploration techniques must be selected based on the properties of the targets and soil conditions.

The shell of an anti-tank mine is made of steel and is about 50 cm in diameter and buried at a depth of about 0.5-1 m, whereas anti-personnel mines (plastic mines) are filled with explosives in a plastic shell with a diameter of 10 cm or less and contains a metal detonator weighing several tens of grams. While anti-tank mines can be detected using a magnetic sensor or electromagnetic induction sensor, anti-personnel mines have detonators made of non-ferrous metals, so a magnetic sensor cannot be used, but an electromagnetic sensor with high sensitivity can be used. This type of electromagnetic induction sensor is normally referred to as a metal detector. On the other hand, GPR uses electromagnetic wave reflections from metallic and non-metallic objects, therefore it is suitable for detecting the plastic shell of anti-personnel mines. Optical camera and infrared camera can be used for detection of explosive objects on the ground surface.

Dual Sensor for Landmine Detection

Electromagnetic induction sensors (metal detectors) have been primarily used to detect anti-personnel mines. Although metal detectors developed for landmine detection are highly reliable, they also detect any metal fragments other than the metals contained in landmines, so excavation and removal work take an enormous amount of time. As a means to solving this problem, the development of a “dual sensor" that combines a metal detector with GPR was started around 2000. We started developing a dual sensor ALIS in 2002 (Sato, et. al., 2012). The most important technical feature of ALIS is that it reduces clutter by synthetic aperture radar (SAR) processing (migration) of GPR signals for imaging buried objects.

GPR of ALIS uses an 800 MHz–2.6 GHz step frequency-continuous wave (SF-CW) radar system and uses circularly polarized EM waves with a cavity-back spiral antenna. Another feature is that it acquires GPR data while tracking the antenna position with a 3-axis accelerometer, which enables it to reconstruct images of subsurface objects using 3D migration. When detecting landmines using ALIS, a metal detector is first used to detect a metal object. Then GPR data is acquired in an area of approximately 50 cm x 50 cm around the metal object. The data acquisition takes about 30 seconds and the data processing is performed on an Android smartphone, and instantaneously the two images shown in Figure 1 are displayed on the smartphone screen. Deminer can check the size and the depth of the object by changing the depth images of GPR.

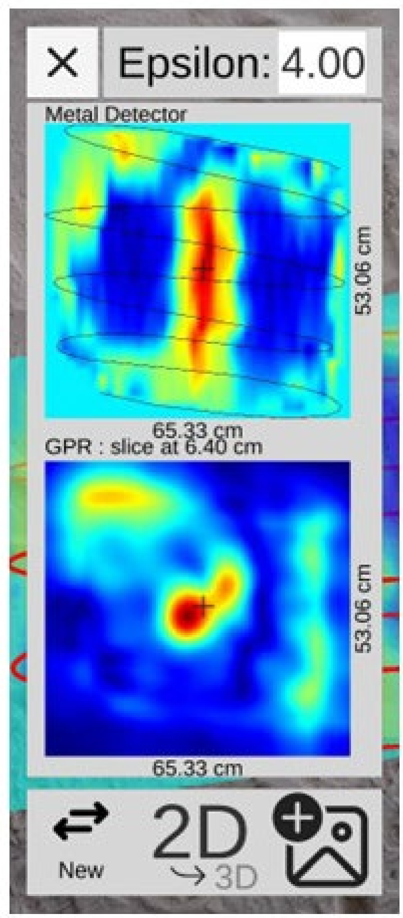

Figure 1. Data image acquired with.ALIS.

Application in Landmine-Affected Countries

Cambodian Mine Action Center (CMAC) started the test of ALIS in minefields in 2018. In January 2019, ALIS was approved for use in minefields in Cambodia and full-scale operation began by CMAC. Based on the results of ALIS field operational tests, 12 ALIS units were provided to CMAC as Japanese government ODA in February 2023.

In Bosnia and Herzegovina, a NATO SPS project (NATO, 2023), jointly organized by the Bosnian Federal Mine Clearing Organization, Tohoku University, and the Netherlands Institute of Applied Sciences (TNO), was conducted between 2020 and 2023 for investigation of effective use of ALIS for demining activities in actual minefields.

GPR function of ALIS is important in Colombia, because they have to find metal-free explosive objects buried by guerrillas. In Colombia, the humanitarian demining team of the Colombian army and Colombian NGO Asociacion Campana Colombiana Contraminas (CCCM) started to use ALIS.

Activities and Prospects for Ukraine

In Ukraine, Russia's annexation of the Crimean Peninsula in March 2014 and the conflict with the Russian military in the eastern Donbas region have been occurring for more than 10 years, and the landmine problem caused by the Russian military has already become apparent (Bechtel et al., 2016). After the Russian military invaded Ukraine in February 2022, a new problem with landmines planted by the Russian military became clear, and Ukraine has also requested Japan for assistance in countering landmines. The landmine problem in Ukraine, which is currently at war, is different from other landmine-affected countries. There have been reports of Russian troops intruding into urban areas and burying landmines inside buildings or in the rubble of destruction as they retreat, hindering reconstruction efforts. ALIS has the ability to visualize not only soil but also objects behind concrete, including reinforcing steel. ALIS can be expected to be used even in situations where conventional metal detectors are useless because they react to reinforcing steel.

Japan may not provide any military support to Ukraine by law, and its contribution to humanitarian demining, a non-military activity, is extremely important. JICA, in cooperation with the Ministry of Foreign Affairs, launched a pilot project to introduce ALIS to Ukraine in January 2023 (JICA, 2023). Because activities in Ukraine by Japanese is limited, we trained deminers of the State Emergency Service of Ukraine (SESU) in Cambodia and Poland. For quick removal of explosive objects in Ukraine, new technologies must be introduced. United Nations Development Programme (UNDP) Ukraine has organized events to demonstrate new landmine detection methodologies in Lyviv, Ukraine in July 2025 (JICA and UNDP, 2025). We attended this event to demonstrate ALIS as shown in Figure 2.

Figure 2. ALIS demonstration in UNDP event, held in Lyviv, Ukraine July 2025. (Courtesy of UNDP).

Many different types of mines and explosives are found in Ukraine. PFM-1, shown in Figure 3, which is also known as a "Butterfly mine", is an anti-personnel land mine of Soviet and Russian production commonly found in Ukraine. PFM-1 can be widely spread on the ground surface from airplanes, and is very difficult to find because of its small size and color. Figure 4 shows horizontal slice GPR images obtained by ALIS.

Horizontal slices are shown every 4mm in depth. The target is a PFM-1 buried at 5cm depth in dry sand. We can see a red circular image of PFM-1. Deminers will observe these images on a smartphone, and the depth of the images can be changed by swiping the screen with a finger. The deminer can understand the shape and the depth of the buried objects, before excavation.

We are discussing with SESU about the effective use dual sensor ALIS in Ukraine, because the current situation in Ukraine is not the typical situation for humanitarian demining. For the time being, we will operate ALIS in Ukraine, and based on the results, we aim to increase the number of ALIS and start full-scale operation.

Figure 3. PFM-1 (Butterfly mine).

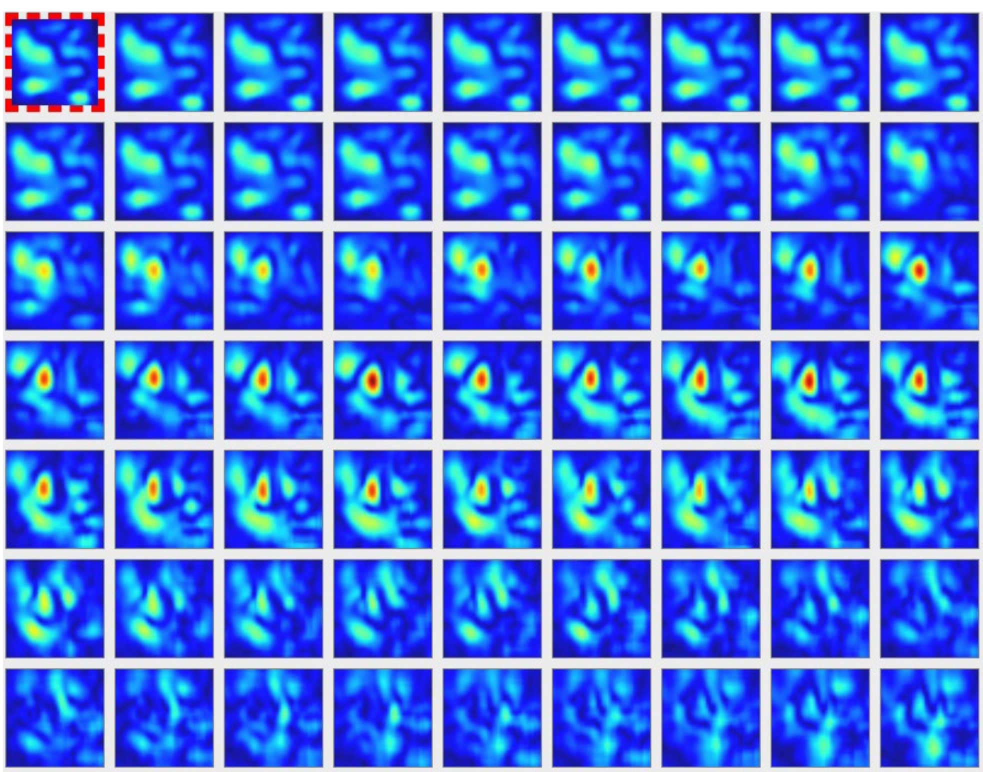

Figure 4. ALIS GPR horizontal images (4mm step) of PFM-1 mine buried at 5cm in sand.

Conclusion

We demonstrated the technical advantages of dual sensor ALIS for detection of landmines. 3-D migration of GPR is the key technology for imaging subsurface objects, which can reduce the clutter, which is caused by soil inhomogeneity, and objects such as grass root and gravels. We think this sensor is quite useful for humanitarian demining. We sincerely hope that the war in Ukraine ends soon, and humanitarian demining operation can be started for the safety and economic recovery.

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Author Bio

Motoyuki Sato received the B.E., M.E degrees, and Dr. Eng. degree in information engineering from Tohoku University, Sendai, Japan, in 1980, 1982 and 1985, respectively. Since 1997 he has been a professor at Tohoku University until his retirement in 2023, and currently he is Professor Emeritus of Tohoku University and Guest professor at Higashi Nippon International University. He is CEO of ALISys Co., Ltd, which he established in 2019. His current interests include transient electromagnetics and antennas, radar polarimetry, ground penetrating radar (GPR), borehole radar, electromagnetic induction sensing, GB-SAR and MIMO radar systems. He developed GPR sensors for humanitarian demining, and they are used in mine affected countries including Cambodia and Ukraine. He received the best paper award at SAGEEP 2021 (ALIS- GPR 3-D Imaging for Humanitarian Demining). He served the technical chair of GPR1996 in Sendai and the general chair of IGARSS2011 Sendai-Vancouver. He is a life fellow of IEEE and a fellow of IEICE.

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☐ User of Geophysical Svcs.	☐ Engineering	☐ Electrical Methods	☐ AEG	☐ Web Site
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☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
	☐ UXO		☐ NSG	
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☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
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