Detection of Buried Mines by Ground Penetrating Radar

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Abstract—Detection of Anti-Tank Mines (ATMs), Anti-Personal Mines (APMs) and Improvised Explosive Devices (IEDs) have become a great challenge for armed forces and paramilitary forces. Ground Penetrating Radar (GPR) is one of the sensors for detection of threats. GPR should detect various targets in different types of soils such as Sand, Red, Laterite and Black Cotton of varying permittivity in dry and wet conditions. Ground also contains significant levels of radar scatterers such as stones, animal burrows, and consequently radar encounters extremely high levels of clutter at short ranges and therefore radar should be able to suppress all this clutter.

Operational environment of GPR are in-accessible areas such as, jungles and non-motorable paths/roads. Therefore low power consumption and light weight are key parameters for the systems.

GPR is made in two configurations depending on the operational environment namely Hand Held GPR and Vehicle Mounted GPR.

Handheld GPR system weighing less than 5Kgs for quick detection and demining operation for Army and Para-military forces respectively in jungle areas where very narrow path-ways exist.
Vehicle Mounted GPR is aimed at scanning and detecting buried objects on roads and tracks that are used by patrolling parties of para-military forces and services.

Target classification of the detected buried targets is indicated with appropriate confidence levels.

This paper describes the system realization and experimental results of Hand held GPR and Vehicle Mounted GPR utilizing low power consuming component selection. Two variants of GPR discussed in this namely Handheld Ground Penetrating Radar and Vehicle Mounted Ground Penetrating Radar.

Keywords—*GPR, buried mine detection, pre-processing, target classification, Handheld Ground Penetrating Radar(HHGPR), Vehicle Mounted Ground Penetrating Radar (VMGPR)*

Ground Penetrating Radar System is aimed at detecting Anti-Tank, Anti-Personnel Landmines (metallic and non-metallic) and Improvised Explosive Devices in a variety of Indian terrain conditions. The system should be compact, portable and ergonomic. The system should provide indication of target/anomaly below the soil by means of an audio signal presented on headphone or through a 3D display. Handheld Ground Penetrating Radar (HHGPR) is a very compact, low power radar and Vehicle Mounted Ground Penetrating Radar (VMGPR) is mounted on the bonnet of a vehicle to detect targets buried at more depth.

This paper is organized as follows. Section I describes the operational scenario of GPR, Section II describes various types of Indian soils in which GPR is operating. Section III describes the various types of targets detected by GPR. Section IV, V and VI describes two types of indigenous Ground Penetrating Radars developed by LRDE. Field results for detection of various targets by indigenous GPRs are shown in Section VII.

I. OPERATIONAL SCENARIOS OF GPR

Anti-Tank Mines (ATMs), Anti-Personnel Mines (APMs) and Improvised Explosive Devices (IEDs) have become a great challenge for armed forces and paramilitary forces. There are a number of methods

to detect these threats. Ground Penetrating Radar (GPR) is one of the sensors for detection of threats. GPR should detect various targets in different types of soils of varying permittivity in dry and wet conditions. The ground also contains significant levels of radar scatterers such as stones, animal burrows, as well as man-made detritus and consequently, radar encounters extremely high levels of clutter at short ranges which radar should be able to suppress. So the radar should be able to suppress all this clutter.

II. TYPES OF SOIL

Soils are three dimensional natural bodies consisting of unconsolidated mineral and organic materials. At all scales of measurements, soils are exceedingly complex and variable in biological, chemical, physical, mineralogical and electromagnetic properties. These properties influence the propagation velocity, attenuation and penetration depth of electromagnetic energy and the effectiveness of Ground Penetrating Radar (GPR). Knowledge of soils and soil properties is therefore useful and often essential, both in the design and operation of GPR surveys. The types of soil of interest can be classified into the following categories:

- **Red Soil:** These soils are quite wide in their spread. The red soils are of different types: Red sandy soil, Red loamy soil and Red-Yellow soil.
- **Laterite soil:** Laterite soils are generally of porous clay in texture.
- **Black soil:** Black soils are loamy to clayey in texture.
- **Alluvial Soils:** These soils are the most fertile amongst the Indian soils.They vary from sandy loam to clayey loam.
- **Desert soils:** These soils are sandy in nature.

A. RED SOIL

The red soils are of different types: Red sandy soil, Red loamy soil and Red-Yellow soil. The silica-alumina ratio of the clay fractions is 2.7:2.46.

B. LATERITE SOIL

Laterite soils are generally of porous clay in texture. Lateritic soils are formed by the intensive pedological process called laterization. The laterite soils are characterized by a compact to vesicular mass in the sub-soils horizons composed essentially of mixture of the hydrated oxides of aluminum and iron.

C. BLACK SOIL

These soilscover a large area throughout the southern half of the peninsula, the Deccan Plateau, greater part of Maharashtra State, western parts of Madhya Pradesh and Andhra Pradesh, and some parts of TamilNadu State.The black soils or regurincludes a large number of physiographic regions, each within a zone having its own combination of soils.

D. ALLUVIAL SOIL

The so-called alluvial soils of India form an ill-defined group. Various types of alluvium are amongst the Indian soils. The large expanse of these soils is yellowish to brownish and their common feature is the presence of kankar or lime nodules intermixed with soil at varying depths.

E. DESERT SOIL

These soils are sandy in nature. A large part of the arid region in Rajasthan and part of Haryana, lying between the Indus and the Aravallis, is affected by desert conditions of recent geological origin. This part is covered under a mantle of blown sand which inhibits the growth of soils. Some of the desert soils contain high percentage of soluble salts,

III. TYPES OF TARGETS DETECTED BY GPR

The different types of targets to be detected using GPR-handheld system are Anti-Personnel MinesAnti-Tank MinesImprovised Explosive Devices.

A. ANTI-PERSONNEL MINES (APM)

Anti-Personnel mine is designed to be exploded by the presence, proximity or contact of a person, stepping on them, pulling on a wire or simply shaking them. Also when an object placed over them is removed, will incapacitate injure or kill one or more persons. APM are designed to kill or injure enemy combatants asopposed to destroying vehicles. Some types of Anti-Personnel Mines can also damage the tracks or wheels of armoredvehicles. APM pose the greatest long term (post-conflict) risk to humans and animals since

they are typically designed to be triggered by any movement or pressure of only a few kilograms. In general, APM are mostly cylindrical objects with a diameter between 4 and 20cm. The diameter of a typical modern APM varies between 5.5 and 10 cm, but roughly 50% of all laid mines have a diameter larger than 10 cm. The mines are laid in such a way that the cylinder's rotational axis is almost vertical. The height of an APM varies typically between 3 and 8 cm.

B. ANTI-TANK MINES (ATM)

Mines designed to be detonated by the presence, proximity or contact of a vehicle as opposed to a person that are equipped with anti-handling devices, are considered as Anti-Tank Mines. They are designed to immobilize or destroy vehicles and their occupants. Anti-tank mines are typically larger than anti-personnel mines and require more pressure to detonate. More modern anti-tank mines use shaped charges to focus and increase the armour penetration of the explosives. Anti-tank mines typically also have a cylindrical geometry, but their dimensions are several times larger than those of APM. The operational burial depth of an APM is less than 20 cm, while that of ATM is up to 100 cm.

C. IMPROVISED EXPLOSIVE DEVICES(IED)

An Improvised Explosive Device (IED), also known as a roadside bomb, is a homemade bomb constructed and deployed in ways other than in conventionalmilitary action. It may be constructed of conventional military explosives, such as an artillery round, attached to a detonating mechanism. IEDs may be used by anti-national elements in unconventional warfare.

An IED typically consists of an explosive charge (potentially assisted by a booster charge), a detonator, and an initiation system, which is a mechanism that initiates the electrical charge that sets off the device. An IED designed for use against armored targets such as personnel carriers or tanks will be designed for armour penetration, by using either a shaped charge or an explosively formed penetrator. IEDs have Explosive whose relative dielectric constant is in the range of 2.3 to 2.8 will become difficult to detect in dry desert soils whose relative dielectric constant is in the same range. Dielectric constant of explosives in the same range as soils can make the detection of mines/IEDs with minimal air voids more difficult. IED depth of burial has gone upto the level of 6-10 feet. Quantity of explosive has also increased upto 70-80 kg. IEDs are used in marshes, mud lands, thick bushy forests, mountains etc.

IV. SYSTEM REALIZATION

A. HANDHELD GPR (HH GPR)

Keeping in view the operational requirement, detection capability in the conditions mentioned in Section II &III, Handheld GPR has been realized by designing DDS based waveform generator, Receiver card, Signal, Data & Image Processing Card. Stepped Frequency Continuous Waveform (SFCW) were utilized in a band of 500 MHz to 3500 MHz. Sweep speed of 0.5 – 1.5 m/s were considered in the system. An HMI which controls the system operation and indicates the detection of targets through LED was designed. Audio generation algorithms based on depth and RCS were implemented, signal processing, pre-processing, post processing and optional display have been designed in house.

B. VEHICLE MOUNTED GPR (VM GPR)

Vehicle Mounted GPR is designed with an array of antenna in order to sweep a swath equivalent to the width of a commercial vehicle (Tata Safari). The vehicle can travel at speeds between 5 Kmph to 15 Kmph. Antenna is designed to be mounted in front of the vehicle with an antenna mounting structure. It operates between 100 MHz to 3100 MHz utilizing SFCW.

Electronics unit consisting of waveform generator, receiver, signal processor, image processor and storage card is housed in the vehicle. GPS for location identification and distance measuring unit (DMI) are mounted on the vehicle. A 3D imaging system has been developed in house and provides classification with a confidence level. The system is capable of operating with a battery and in emergencies vehicle battery can be utilized as a source of power.

S. No.	Feature	Handheld GPR	Vehicle Mounted GPR
1	Detection Capability	APM : 20 Cms ATM : 30 Cms IED : 50 Cms	APM : 20 Cms ATM : 50 Cms IED : 1 Mts
2	Depth Resolution	≤2 Cms	≤2 Cms
3	Technology	SFCW Technology (3 GHz BW)	SFCW Technology (3 GHz BW)
4	Weight	< 5 Kgs	< 70 Kgs
5	Power consumption	< 15 W	< 80 W
6	Target Identification	Audio Signal through headphones	Visual Indication
7	Display	Optional : 2D display	3D display
8	Classification	Available based on depth & RCS	Available based on depth & RCS

V. EXPERIMENTAL SETUP

Three wooden boxes of dimensions 200 cm x 100 cm x 50 cm are filled with dry, red and black cotton soils. Targets of interest can be buried in these boxes upto a depth of 50 cm and data collection can be performed for both types of radars. An overhead crane is mounted over these boxes to simulate the speed of a vehicle and data can be collected.

Figure 1: Experimental setup of GPR at LRDE

VI. GROUND PENETRATING RADARS DEVELOPED BY LRDE

LRDE has developed two Ground Penetrating Radars one handheld system and one vehicle mounted system. Handheld system is very compact, low power, light weight system with provides indication of target/anomaly below the soil by means of an audio signal presented on headphone. Handheld GPR system has an optional display feature.

Vehicle Mounted Ground Penetrating Radar will display data in three dimensions and it has Automatic Target Recognition and Classification.

Figure2 and Figure 3 below shows the indigenously developed Handheld Ground Penetrating Radar (HHGPR) and Vehicle Mounted Ground Penetrating Radar (VMGPR).

Figure 2: Indigenously realized Handheld GPR

Figure 3: Indigenously Realized Vehicle Mounted GPR

VII. DETECTION RESULTS WITH INDIGENOUS GROUND PENETRATING RADARS

Field experiments were conducted for detection of various targets like APM, ATM, IED and metal plate at various depth and in various types of soil. The figure4 to figure 7 below shows the detection results in various soils at various depths.

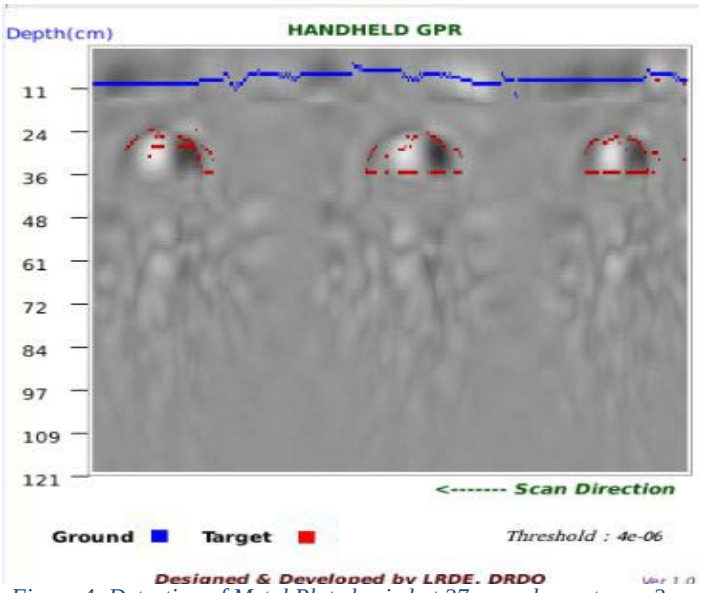

Figure 4: Detection of Metal Plate buried at 27cm and swept over 3 times

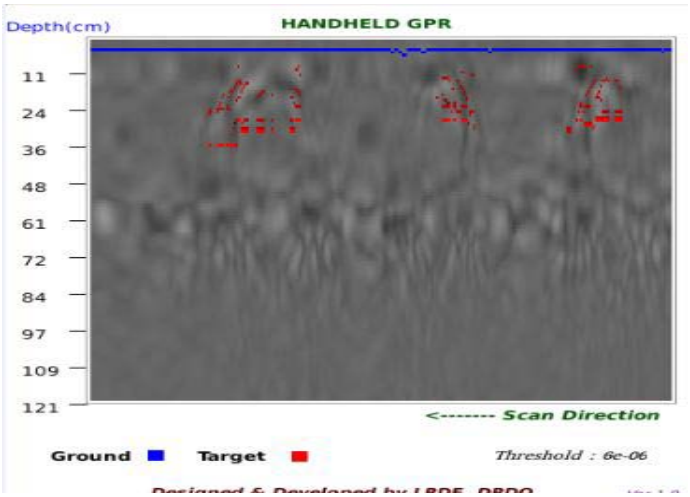

Figure 5: Detection of ATM buried at 9cm and swept over 3 times

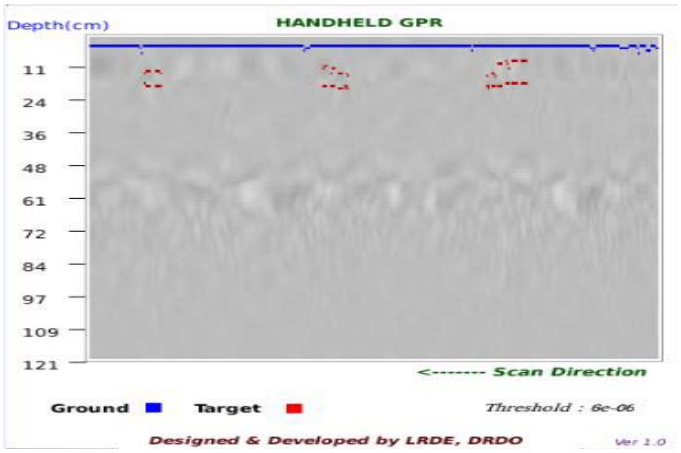

Figure 6: Detection of IED buried at 9cm and swept over 3 times

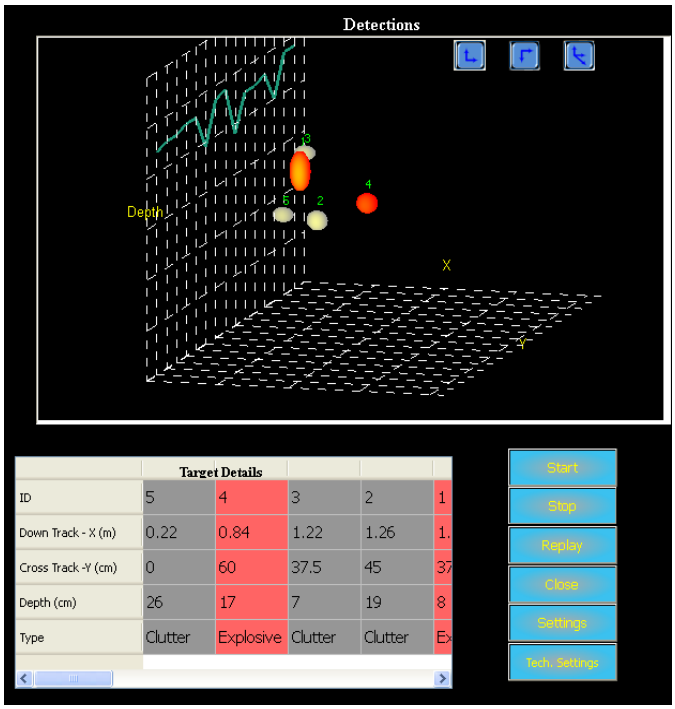

Figure 7: Detection of Influence Mine buried at 18 cm

VIII. CONCLUSION

LRDE, DRDO has successfully developed fully indigenous Handheld Ground Penetrating Radar (HHGPR). The system is very compact, low power and light weight. The field trials of the indigenous Handheld Ground Penetrating Radar (HHGPR) are in progress. The System Integration of Vehicle Mounted Ground Penetrating Radar (VMGPR) is also in progress.

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REFERENCES

[1] J. D. Daniels, *Surface-Penetrating Radar*. London, U.K.: IEE, 1996.

[2] Claerbout J.F., *Imaging the Earths Interior*,Blackwell Scientific Publications, 1985.

[3] Harrington, Roger, F. *Time-Harmonic Electromagnetic Fields*, IEEE Press, reprinted in 2001.

[4] Jones, D.S. *The Theory of Electromagnetism*, Pergamon Press, 1964.

[5] Stolt, R.H., 'Migration by Fourier Transform', Geophysics, Vol. 43, Issue 1, pp. 23- 48, Feb. 1978.

[6] Soumekh, *Synthetic Aperture Radar Processing*, John Wiley and Sons, United States, 2002

[7] Matlab 6.5 Release 13, The Mathworks Corporation, 2002.

[8] Yilmaz, O. *Seismic Data Processing*. Tulsa, USA: Society of Exploration Geophysicists, 1987, ch.4.

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