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DEVELOPMENT OF STRATEGIES FOR SUB-SURFACE OBJECTS AND LANDMINE DETECTION

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CANDIDATE'S DECLARATION

I, Chhavi Tomar, Roll No. 2K20/GEO/06 student of M.Tech (Geoinformatics), hereby declare that the Dissertation titled "Development of Strategies For Sub-Surface Objects And Landmine Detection" which is submitted by me to the Multidisciplinary Centre for Geoinformatics, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi CHHAVI TOMAR

Date: May 31, 2022

CERTIFICATE

I hereby certify that the Project Dissertation titled, "Development of Strategies for Sub-Surface Objects and Landmine Detection" which is submitted by me to the Multidisciplinary Centre for Geoinformatics, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 31/5/22

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ABSTRACT

The immense operational and intelligence potential of remote sensing continues to entice military strategists around the world. Microwave remote sensing, for example, has the ability to detect underground landmines, particularly along the country's western borders, which are covered in vast deserts devoid of vegetation. In the current study, this issue has been investigated.

Landmines are small explosive devices that are planted at shallow depths to kill or incapacitate an unsuspecting opponent. Microwave frequencies in the X-band (10 GHz frequency and 3 cm wavelength) may have adequate penetration and resolution for landmine detection at shallow depths where landmines are buried, but the backscattered image from these shallow buried landmines is severely cluttered, and mine feature extraction remains the main problem in landmine detection. Several signal and image processing approaches that have been proposed to handle the problem either have functional limits or produce a large number of false alarms.

The major focus of this research is to look into the methodologies and processes for detecting subsurface and surface targets utilizing microwave data. Landmine detection up to a depth of 10cm has been tested in the lab and in the field using microwave X-band frequency (10Ghz, 3cm). In the laboratory, data was collected using a dummy antitank landmine (without explosives) buried in dry smooth sand at various depths, as well as a live antitank mine (in the field). Raw data is processed using two separate methods: full image processing and local window processing. Data pre-treatment entails a series of image processing processes prior to segmentation utilising Otsu's and maximum entropy-based thresholding. Local window-based processing is found to highlight mine-like and non-mine-like characteristics more precisely than whole image processing, allowing for straightforward segmentation utilising two thresholding methods.

The usage of local window processing, on the other hand, may result in a longer processing time. The two thresholding methods have a minor difference in performance, with the maximum entropy-based method performing somewhat better in segmenting mine-like features with low variance from surrounding clutter. The findings were confirmed using the known location of the mine that was used in the trials. The presence of a landmine is indicated by a detection figure in the range of 30-80. The backscattered electric field was theoretically calculated using Daniels' suggested electromagnetic model. The backscattered electrical field detected was acquired from a segmented suspected landmine-containing zone.

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Chhavi Tomar

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
AP	Anti-Personal
AT	Anti-Tank
CFAR	Constant False Alarm Rate
EIT	Electrical Impedance tomography
EM	Electro Magnetic
FNA	Fast Neuron Analysis
GPR	Ground Penetrating Radar
HFA	High Frequency Attention
HFM	Histogram Fitting for Mapping
HPDI	High Pass Division Index
IED	Improvised Explosive Device
LIBS	Laser induced breakdown spectroscopy
MD	Metal Detector
MMWR	Millimeter Wave Radar
NQR	Nuclear Quadrupole Resonance
PFNA	Pulsed Fast Neuron Analysis
PFTNA	Pulsed Fast Thermal Neuron Analysis
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SWIR	Short Wave Infra-Red
TCA	Transfer Component Analysis
TIR	Thermal Infra-Red
TNA	Thermal neuron Analysis
UXO	Unexploded ordinance
VENUS	Vibration enhanced underground sensing
VNIR	Visible/Near Infra-Red
VOIED	Victim Operated IED

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

About one third of the world's countries have long suffered from the problem of landmines that threatens the citizens. It was not only the security forces, but also the insurgents and guerrillas who have used landmines as a weapon of their choice in civil wars and insurgencies for decades. Landmines used on battlefields are illegal under the international humanitarian law, which protects people who have left armed conflict or aren't involved in it. Due to the lack of effort being made to clear landmines from affected areas, many years after a conflict has ended, landmines continue to pose a threat to civilians. The restrictions limit freedom of movement and deprive people of access to basic necessities, hindering post-conflict reconstruction efforts and the implementation of sustainable development goals (SDGs). This problem damages the social and economic development, and it is mainly civilians who suffer the horrific consequences. Stepping on a mine will often results into killing or injury of one or more people and it have lifelong consequences on the victims and their families. Also, the presence of mercury and lead in most of the mines contaminates the vast areas of valuable land which directly results into compromising food production and destroying livelihoods.

1.2 BACKGROUND TO REMOTE SENSING

Remote sensing provides information about objects at or near the surface of the Earth and atmosphere based on radiation reflected or emitted from those objects. The information is usually captured at a distance from above in the form of image data [2]. Remote sensing is considered as a potential approach to detect objects under and over the Earth surface. It usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere, using sensors onboard airborne (aircraft, balloons) or space-borne (satellites, space shuttles) platforms. The electromagnetic radiation is normally used as an information carrier in remote sensing. Remote sensing employs passive and/or active sensors. Passive sensors are those which sense natural radiations, either reflected or emitted from the earth. On the other hand, the sensors which produce their own electromagnetic radiation, are called active sensors [3]. Remote Sensing can be broadly classified as optical and microwave. In optical remote sensing, sensor detect solar radiation in the visible, near-infrared, middle-infrared and thermal-infrared wavelength regions, reflected/scattered or emitted from the earth forming images resembling photographs taken by camera/sensor located high up in space [4]. Other than that, there are four Types of resolution:

1. **Spatial Resolution**: Spatial resolution is defined by the size of each pixel within a digital image and the area on Earth's surface represented by that pixel.
2. **Spectral resolution**: Spectral resolution describes the ability of a sensor to define fine wavelength intervals.
3. **Temporal resolution**: Temporal resolution is the time it takes for a satellite to complete an orbit and revisit the same observation area.
4. **Radiometric resolution**: Radiometric resolution is the amount of information in each pixel, i.e., the number of bits representing the energy recorded. [5]

1.3 TARGET DETECTION

Target Detection is binary hypothesis testing in which we decide whether a particular object i.e., target is present or not. Target is primarily an object. Basically, there are two types of targets Natural and Manmade. Apart from these two types of target another type is also there viz. Mixed type target which is the mixture of both natural and manmade. Table1.1 shows the classification of targets based on different criterion. Spectral properties of natural target are consistent (Spectra is known) so detecting them is easy whereas manmade targets show much variability in spectral properties so detecting them is quite difficult as compared to the natural one [6].

Target detection in remote sensing imagery, mapping of sparsely distributed materials, has vital applications in defence security and surveillance, mineral exploration, agriculture, environmental monitoring, etc. From a target detection perspective, high-resolution multispectral imagery has been used for identifying common land use objects such as buildings, roads, vehicles, and ships [7]. Hyperspectral imagery offers appropriate baseline spectral data with finer spectral bandwidth required for typical target detection problems. Target detection also serves its purpose in military application like detection of enemy weapons, men, etc. Target Detection process involves six stages which are Detection, Identification, Recognition, Classification, Quantification and Automation [8].

Table 1.1: Classification of Targets

Criterion	Target Type	Examples
Location Based	Surface	Buildings
	Sub-Surface	Submarines
	Aerial	Aircrafts
Condition	Camouflaged	Hideouts
	Originated	Minerals
	Buried	Landmines
Shape	Point	Car
	Linear	Railway Line
	Area	Building, Houses, Village
Size	Pixel	Tank
	Sub-Pixel	Aeroplane
User Defined	Military	Strategic, operational, tactical
	Geological	Minerals

1.3.1 Issues and Problems in Target Detection

- Variations in the shape and the scale of the spectral signatures of the same material in different pixels along the image are known as spectral variability. In simple words, we can say that spectra should be as distinct as possible. Also, large variation should be there for different objects but inter-variation should not be there for same objects.
- At different time, there will be different spectra for same object so spectra start clashing also, if spectral variability increases it will create problem. To solve this, we need spatial data of high resolution to identify the objects or to detect targets. This problem happens more in urban areas and military materials.
- Complexity of data is too much in fine resolution.
- High dimensionality which results into high complexity and redundancy.
- Target smaller than the resolution of the data might get lost in the pixel which we cannot found out using spatial data only. It will be hard to locate such target in the image. Therefore, to overcome this super-resolution could be used.

1.4 ISSUES IN LANDMINE DETECTION

Imaging of buried targets under the rough ground is a challenging inverse scattering problem with many applications in engineering such as land mine detection and remote sensing of archaeological artefacts. Landmines are weapons, usually buried, that explode when stepped on and are designed to injure or kill, leaving long-term psychological effects and posing a financial burden to the community [9]. Anti-tank and anti-personnel mines come in all shapes and sizes, and can be encased in metal, plastic, wood or nothing at all. Their fusing mechanism varies from simple pressure triggers to trip wires, tilt rods, acoustic and seismic fuses, or even light- or magnetic influenced fuses. They can be embedded in a field cluttered with various materials and objects, buried underground at various depths, scattered on the surface, planted within buildings, or covered by plant overgrowth [10]

Landmine (LM) inspection systems that are reliable are in high demand. The loss or absence of maps or information about the landmine types used or the areas where they were originally placed, the change of landmine locations due to climatic and physical factors, the large variety of types of antitank (AT) and antipersonnel (AP) landmines, and the high cost of locating and removing landmines are all obstacles to removing these landmines. Individuals have been put in danger by landmines' sensitivity to detonation with time or because to atmospheric variables [9].

Several approaches for demining, or the identification and removal of buried landmines, have been designed and developed. Depending on the type of mine casing, the explosive material, and the soil, each method is preferred for detection under certain conditions. Most landmine detection techniques, as shown in Figure 1.1, consist of three main units: a sensor to capture a landmine signature, a signal or image processing unit to manage the acquired data in a suitable format for detection, and a decision-making unit to determine whether or not a landmine exists [11].

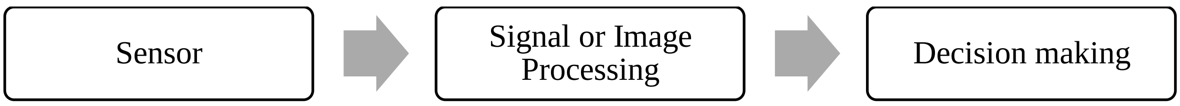


Figure 1.1 Approach for Landmine Detection [11]

The challenge of landmine detection is not only to develop techniques that can meet this demanding problem, but to also tailor such techniques to local conditions. It is difficult to apply any one technique unless the nature of the mine, soil and background clutter is well known, and it is inconceivable that a single detection technology will be able to meet all needs. A fusion of systems is needed as a solution to the landmine detection problem. Radiation-based techniques have the unique ability to identify the presence of an explosive material in an anomaly detected by other methods [12].

1.5 LITERATURE REVIEW

The requirement of active microwave remote sensing has usually been felt in obtaining images of sub-surface (both ground and under-water) materials and objects and also in areas of thick foliage, forest, vegetation or camouflage cover. Microwave frequencies due to their longer wavelengths have the capability to penetrate fog, cloud, vegetation and even top layer of soil. Active microwave data may therefore be utilized for detection of inert land mines, camouflage paints and fabrics.

The penetration depth of different radar bands can vary. Longer the wavelengths, the longer will be penetration depth of wave. In comparison of C-band, X-band, and L- band, the shortest wavelength X band has the least penetration power in forest areas while L band penetrates forest canopies down to the tree trunks (Lillesand et al., chap.8) [13]. An L-band (20 cm wavelength) signal will penetrate about 10 times deeper than Ku band (2 cm wavelength) signal thus enabling access to a volumetric layer near the surface of target (Elachi C, 1987) [14]. Shape and orientation of the target affects differently the microwave scattering in different polarizations and therefore polarisation plays an important role in determining the shape and orientation of the target.

A neural network-based classifier was successfully employed for automated detection of buried targets. The system was applied successfully for detection and mapping pipes, cables and anti-personnel landmines (Nuaimy et al, 2005) [15]. Use of neural networks for detection of dielectric cylinders distributed over an area has also been reported by Carosi et al., (1999). Therefore, neural networks in addition to various other advanced computing techniques may be used to extract various properties of buried targets such as shape.

Shihab and Al-Nuaimy W (2005) [15] demonstrate a method for automatically merging data from many radargrams over a site to precisely recognise the geometry of any buried cylinders. The 3D radar data set's orientation and inclination of linear reflectors are utilised to adjust for erroneous assumptions about the target radius and electromagnetic propagation velocity, which yields substantially more accurate descriptions of the geometry of buried pipes in the data, and can then be utilised to generate 3D profiles of medium permittivity. With the advancement in processor speeds, such site-level processing and interpretation have become more practical. On a simulated test site, promising preliminary results were reported.

For high-resolution synthetic aperture radar (SAR) images, Yu W, et al. (2016) [16] proposed a new super-pixel-based constant false-alarm-rate (CFAR) target detection technique. Segmentation, detection, and grouping were the three stages of the detection algorithm used. A super-pixel generation algorithm was used to segment the SAR image during the segmentation stage. Even in multitarget settings, the clutter distribution parameters for each pixel can be adaptively approximated in the detection stage depending on the super-pixels created. For detection, the two-parameter CFAR test statistic might be used. In the clustering stage, the identified super-pixels were clustered to provide candidate targets using hierarchical clustering. The suggested algorithm's effectiveness was illustrated using mini-SAR data.

A new fused approach based on the contourlet transform was described by Yong-an Zheng, et al. (2006) [1] to fuse multi-band Synthetic Aperture Radar (SAR) pictures. In this approach, Image multiresolution, anisotropy, and directional expansion were all provided by the contourlet transform. It was more efficient in presenting image edges than wavelets. The directional high-frequency coefficients were fused using this method. An average fusion rule was employed for the lowpass coefficients. The higher the value of Edge Information Measurement, the better the coefficients for fusion for directional high-frequency coefficients. The suggested solution addressed the issue of wavelet-based fusion methods losing edge information. Finally, when two bands SAR image fusion was compared to the wavelet fused approach, the vision effect was visible, as well as the statistical assessment elements for fusion.

The use of co-occurrence texture metrics to provide information on varied building densities inside a town structure was investigated by Fabio Dell'Acqua, et al (2003) [17]. They used texture measures as a technique of block analysis and classification to try to improve the pixel-by-pixel categorization of an urban region. Also, in this study, some intriguing ideas about the ideal window dimension to consider for texture measures, as well as the most relevant measures were discovered. Furthermore, it was also suggested that medium-resolution, publicly available satellite synthetic aperture radar images could be used for a more refined urban study.

Ihab Makki, et al. (2017) [18] described the numerous signal processing algorithms used in the framework for hyperspectral image processing and target detection, as well as the findings of several studies that used hyperspectral imaging for landmine detection. In this study they found out that a comparative investigation of different classification algorithms in various settings should be addressed in order to get a trustworthy detection. In order to maximise the capturing time and minimise the computational time, one must consider the effect of imager elevation, which affects the spatial resolution, the number of pixels in each frame, and the imager holder velocity. Furthermore, the advancements made in the detection of landmines using hyperspectral imaging and to identify possible future research directions in order to improve detection in real-time operation mode were also highlighted in this study.

Wassai and Kalyankar (2011) [19]created a new qualitative assessment for assessing the spatial quality of pan sharpened images using a variety of spatial quality indicators. In addition, this article compared different picture fusion algorithms based on pixel and feature fusion methodologies. This research examined the comparative studies conducted by the best different types of Image Fusion techniques based on pixel level, such as HFA, HFM, and HIS, and compares them to feature level fusion methods, such as PCA, SF, and EF image fusion techniques. Experiments with spatial and spectral quality matrices revealed that the SF technique based on feature level fusion keeps the spectral integrity of the MS image while improving the spatial quality of the PAN image as much as possible. If the purpose of the merging is to produce the best representation of the spectrum information of a multispectral image and the spatial details of a high-resolution panchromatic image, the usage of the SF-based fusion technique is strongly advised. Because in its Component Substitution Fusion techniques in conjunction with spatial domain filtering was used. To reduce colour distortion, the contribution of individual bands to the fusion results using a statistical variable between the brightness levels of the image bands was modulated. Since MG produced the smallest gradient results, the SG analytical technique was considerably more useful for measuring the gradient than MG. Because our proposed method, HPDI, produced the smallest difference ratio comparing image fusion methods, it is strongly advised to utilise HPDI for determining spatial resolution because of its mathematical precision as a quality indicator.

Abdelhak M. Zoubi et. al., (2002) [20] provided different signal processing approaches for use with GPR and used receiver operating characteristic curves to compare their detection performance. They discovered that the method for estimating the background and the number of traces used in this calculation have an impact on the analysis outcomes. In terms of lowering the likelihood of false alarm, an adaptive background estimate produces the best results. The Kalman filter explicitly modelled the signal return's background component, whereas the others are essentially various methods of identifying a change in a background-adjusted trace. The detection performance comparison framework presented here is thought to be extremely useful in the refinement, development, and extension of existing and new landmine detectors. They also concluded that other sensors would also require similar detection algorithms to be developed and verified and It is also possible that a fusion system using many approaches and sensors may emerge.

The capacity of different optical wavebands – visible/near infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR) – to detect surface-laid and buried mines was discussed in this study. The phenomenology that influences performance in various bands was examined. Hyperspectral imagers were typically developed and built for general-purpose remote sensing applications, and they generally fall short of mine detection criteria. The equipment as well as the requirements for such imagers were described. Some mine detecting experiment findings were shared. In the VNIR and SWIR, reliable daytime detection of surface-land mines was proven in non-real-time, regardless of sun angle, time of day, and season. Low-speed ground vehicles and, more recently, airborne platforms had exhibited real-time analysis, which was required for military applications. [21]

K.C. Tiwari et al. [22] showed the results of using microwave remote sensing to identify and estimate the depth of shallow buried landmines (subsurface objects). The results of an experimental setup of a ground-based scatterometer working in the microwave X-band were shown by the authors. The experiment's raw data was processed utilising a number of image processing procedures, with a region of interest segmented using Ostu and a maximum entropy-based thresholding method for subsequent processing. The depth of a subsurface object was estimated using a genetic algorithm.

In their article, Varsha Turkar et al. (2011) [23] compared the land cover categorization capabilities of fully polarimetric versus partially polarimetric SAR data for the C-band and L-band. For classification, an MLC with a complicated distribution and an ANN classifier were employed. By comparing the categorised results of intensity and complex pictures for all conceivable polarisation combinations in L-band and C-band, the change in accuracy due to phase information of SAR data was also analysed. Fully polarimetric data provided the maximum accuracy in all combinations, and it was not substantially different from the complex partial polarimetric (HH, VV) combination. The accuracy of partial polarimetric combinations varies depending on the type of land cover. Furthermore, the authors concluded that combining the three components of van Zyl decomposition with the combination of X-, C-, and L-band improved accuracy marginally.

The Contourlet transform was used by Yong-an Zheng et al. [1] to fuse multi-band SAR pictures. Image multiresolution, anisotropy, and directional expansion were all provided by the contourlet transform. It was more efficient in presenting image edges than wavelets. The directional high-frequency coefficients were fused using that method. An average fusion rule was employed for the low-pass coefficients. It was also observed that the higher the value of Edge Information Measurement, the better the coefficients for fusion for directional high-frequency coefficients.

1.6 RESEARCH GAP

Following is a list of significant research gaps that need to be researched as a result of a comprehensive examination of the literature:

- There is a dearth of indigenous effort in creating models for both subsurface landmine detection and surface target detection employing microwave remote sensing and optical remote sensing.
- The majority of scientists have employed image analysis, electromagnetics, and soft computing approaches on their own. For landmine identification, there aren't many models that combine these three strategies. Several of the models examined do not include information on the depth of the landmine, despite the fact that these are major variables of the landmine.
- Surface roughness effects are being investigated to see whether they may be reduced to improve detection of buried things. This is something that the majority of the models we looked at overlooked. Multipolarization microwave data and associated modifications for surface texture minimization could be very valuable in improving landmine detection, hence this is a topic that needs to be looked into more.

1.7 RESEARCH OBJECTIVES

1. Critical Review of current available Sub-Surface Objects and Landmine Detection.
2. Review of terrain implications on Sub-Surface Objects and Landmine Detection.
3. Sub-Surface Objects and Landmine Detection using scatterometer.

1.8 ORGANISATION OF THESIS

This thesis has been organised into six chapters. The first chapter introduces the motivation leading to the problem formulation for this study and the background to remote sensing, target detection approaches and landmine detection. Also, the issues of target detection and landmine detection are discussed in this chapter. Next the research gaps and research objectives has been listed. Then chapter 2 provides the basic introduction to Landmines, their classification and alternative strategies used for Landmine Detection. After that in chapter 3 there is brief introduction about the physical geography of India and terrain implications on the detection of sub-surface object and landmine. Later chapter4 discusses the proposed methodology of landmine detection. Then chapter 5 provides the summary of results of the study. Finally, Chapter 6 provides the conclusion and the future scope for the various target detection approaches used in this project thesis.

CHAPTER 2
ALTERNATIVE STRATEGIES FOR LANDMINE DETECTION

2.1 INTRODUCTION TO LANDMINES

A landmine is an explosive device that is used to destroy or damage vehicles, as well as to harm, kill, or restrict the activities of people. Mines can be triggered by direct pressure, electrified barbed wire, tilt rods, command detonation, or a combination of these methods, or they can be victim activated, that is, exploded by the action of their target when walked on or struck. They can also be booby trapped with anti-handling mechanisms, for example, to make removal more difficult [24].

Mines are used as military weapons to secure vital military sites or to obstruct unit mobility by inflicting enemy fatalities and destroying equipment. They can also be used offensively, such as during battles to demolish or damage infrastructures and terrorise civilian populations by denying them access to their houses, farmland, water, highways, schools, care facilities, and other resources. Landmines are frequently employed in IEDs. A landmine's explosives might be employed as the main charge, or the landmine itself could be utilised as a trigger for a Victim Operated IED (VOIED) [25].

Landmines are almost usually concealed and disguised to blend in with their environment, making them difficult to spot. They are frequently buried or disguised in grass, structures, or trees, and are attached to stakes or trees. Landmines are typically laid into patterns to establish consistent obstacles, or along roadways and around vital places in conventional warfare. The locations of new minefields must be recorded on maps, although this is not always accurate [24].

Landmines are frequently set haphazardly by armed parties who are continuously on the move; some mines are even distributed over a large region by aircraft or artillery with no evident or discernible pattern. There are over 600 various varieties of landmines now in use, as well as numerous improvised mines created by armed (opposite) forces involved in combat. They can be divided into two categories: Anti-Personnel (AP) and Anti-Vehicle (AV) mines, often known as Anti-Tank mines, are anti-personnel and anti-vehicle mines [26].

Figure 2.1: Landmine [24]

2.2 TYPES OF LANDMINES

Each landmine has three parts: a container made of metal, wood, plastic, or a combination of these materials, an explosive material made of TNT, RDX, mixed RDX/TNT, Tetryl, or other explosives, and an initiator made of a pressure sensor, an electronic sensor, or any other sensor. Landmines are categorized based on their design or intended target [27].

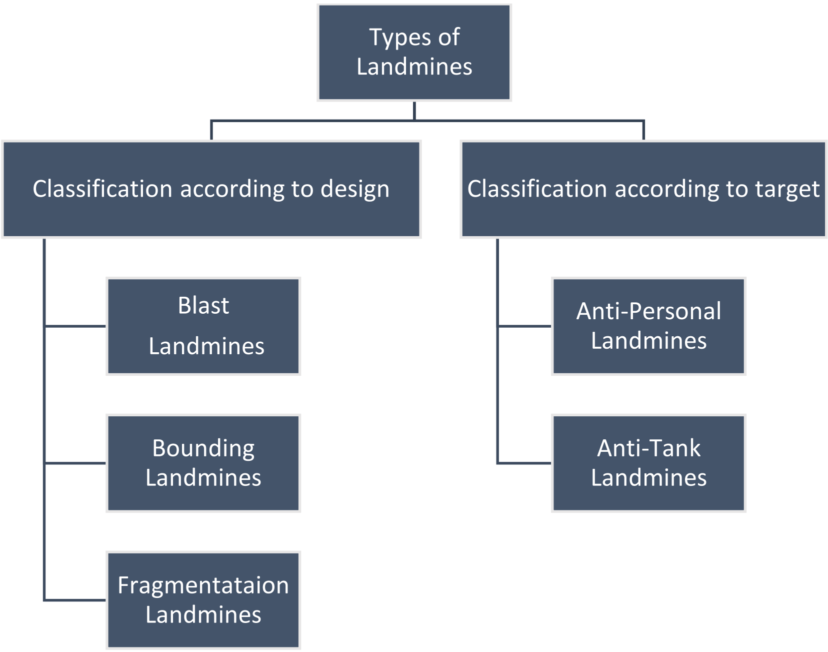


Figure 2.2: Types of Landmines

2.2.1 Classification according to design

Landmines are divided into three groups based on their design: blast, bounding (bouncing Betty), and fragmentation landmines.

2.2.1.1 Blast Landmines

Blast landmines are buried near the surface of the ground and are usually triggered by pressure (such as passing over or stepping on them) or by handling/disturbing.

To detonate, pressure activated mines typically require 5–16 kg of pressure. The primary goal of these mines is to destroy a nearby object, such as a person's foot or leg. A blast landmine is designed to shatter the target into shards, which can result in secondary injuries like infection and amputation.

2.2.1.2 Bounding Landmines

Only a small portion of the initiator protrudes from the ground when these landmines are buried. When the initiator is activated, it fires a propelling charge that propels the mine about 1 metre into the air, causing injuries to the head and chest.

2.2.1.3 Fragmentation Landmines

Landmines of this type can be set up to send fragments in one direction or all directions. These landmines are capable of injuring and killing people from a distance of up to 200 metres. Metal or glass particles are employed in the landmines [10].

2.2.2 Classification according to target

There are two types of buried landmines: Anti-Personal landmines and Anti-Tank landmines, which are classified according to the possible target. The distinctions between the two major categories are shown in Table 2.1. In addition to landmines, unexploded ordnance (UXOs) like as misfired shells or unexploded bombs can still be found buried in previous battlefields, posing an explosive threat.

Table 2.1: Distinctions between Anti-Personal and Anti-Tank Landmine [22]

Category	Anti-Personal Landmines	Anti-Tank Landmines,
Size	0.06-0.2m	0.2-0.5m
Weight	0.1 kg-4 kg (Light)	6 kg-11 kg (Heavy)
Working Pressure	0.5kg	120kg
Target	Human	Vehicle (Tank, etc)
Case Material	Metal, Plastic, Wood	Metal, Plastic

2.2.2.1 Anti-Personal Mines

An anti-personnel (AP) landmine is one that is meant to incapacitate, injure, or kill one or more individuals when it is detonated by the presence, vicinity, or contact with a person. AP mines are normally exploded when trodden on or when a tripwire is pulled, although they can also be triggered off by time or by controlled means [28].

AP mines are basically small explosives that come in a variety of designs and can be located on the ground, buried, or fixed above ground. They are often disguised to blend in with their environment and can be made of wood, plastic, or metal.

Figure 2.3: Anti-Personal Landmine [24]

2.2.2.2 Anti-tank Mines

Anti-Vehicle (AV) mines, also known as Anti-Tank mines, are mines that are designed to cripple or demolish vehicles. Anti-Vehicle mines, like Anti-Personnel mines, can be exploded by pressure, though much more weight is usually required, by remote control, by magnetic influence, or by disrupting a tilt rod (a type of vertical tripwire). A Glass-Fibre-Cable installed on the road can also be used to fire small fin-stabilized Anti-Tank-Rockets from guided AV-Off road mines. They can be placed anywhere between 2-40m from the road, fixed on a tiny tripod, or hung from a tree. AV mines are commonly found on highways, roadsides, trails, tracks, and the road margins since they are designed to destroy cars. AV mines can be found even on well-travelled roadways [24].

AV mines are substantially larger and have a lot higher explosive charge than AP mines. They are usually square or round in shape, with a diameter of 40 cm and a height of 16-23 cm and a height of 10 cm. They are available in a variety of colours and it can be made of timber, plastic, or metal. Charges for AV mines are around 6 kg HE, however they can also be shaped.

Figure 2.4: Anti-Tank Landmine [26]

In addition, AV mines are frequently utilised as the primary component of an IED. The fuse can be placed beneath or inside the mine. As a result, lifting allegedly unfused mines can be risky. A conventional AV mine normally requires a lot of pressure to detonate, roughly 120 kg to 150 kg. This does not mean that persons who weigh less can tread on an AV mine safely. The pressure required to explode AV mines may be reduced as fuse mechanisms fail or are purposefully changed. AV mines are sometimes booby trapped and explodes when disturbed. In certain circumstances, AP mines have been placed on top of AV mines, causing the AV mine to explode as well when activated. [26]

2.3 CRITICAL REVIEW OF CURRENT AVAILABLE TECHNOLOGIES OF SUB SURFACE OBJECTS AND LANDMINE DETECTION

Detecting and destroying landmines and IEDs is a critical step in preventing new victims. Due to the features of these devices and the soil where they are hidden, finding IEDs is a difficulty in Antioquia today. A review of landmine detecting systems is presented here in order to help guide future research on the subject. The goal of these strategies is to reduce the number of false alarms while retaining a high probability of detection, saving time and lowering the risk of injury to the deminer. These methods are summarised in Table 3.1. The detecting principle for each is listed in the second column. The next column summarizes the complexity, cost, speed, safety, Environmental Effects, False Alarm of each [9].

Table 2.2: Alternative methods of landmine detection [30] [31] [32] [33] [34]

Techniques/ Sub- techniques		Sensor	Complexity, cost, speed, safety, Environmental Effects,
Explosive trace Detection	Biological methods	**Dogs:** Dogs exceed the greatest chemical agents and can detect a variety of by-products from mine explosion decomposition; nevertheless, they require ongoing training and their performance deteriorates over time.	High, High, Medium, Medium, high, High
		Rodents: They are taught to scratch the ground with their feet to signal the presence of explosives. Rats offer several advantages over canines, including being less expensive, able to be deployed in huge numbers, being lighter, and being resistant to tropical diseases.	Medium, High, Medium, Medium, Medium, Medium
		Bees: By introducing a combination of sugar and the explosives near their colony, bees are taught to associate the smell of an explosive with food. Bees are limited in their employment since they are difficult to follow, can only work in certain climates, and their efficiency with many sources is unknown, with the possibility that they can only detect the strongest.	Medium, High, Medium, High, Medium, Low
		Plants: Aresa Bio detection company has genetically modified a thale-cress plant called Arabidopsis Thaliana to change colour when in contact with nitrogen dioxide emanating from explosives. This technique has associated problems: nitrogen oxides are also formed by denitrifying bacteria, causing false alarms, these plants do not grow to be high, making it difficult to watch the results, and there is some concern about native plants contamination	Low, High, Low, High, High, Low
		Bacteria: In the presence of TNT, certain genetically modified microorganisms produce fluorescence. The bacteria are sprayed in the minefield, allowed to develop for several hours, and then searched for fluorescence signals. These bacteria may cover enormous areas quickly, however they are extremely sensitive to environmental conditions, and false alarms due to unexplained causes have been reported. There is also no known bacterium strain capable of detecting explosives other than TNT.	High, High, Low, Medium, Medium, Medium

Table 2.2 (Continued)

Techniques/ Sub-techniques		**Sensor**	**Complexity, cost, speed, safety, Environmental Effects, False Alarm**
Explosive trace Detection	Chemical methods	**Mass and ion mobility spectrometry:** A sample of air being ionised in a vacuum chamber during mass spectrometry. Ion mobility spectroscopy involves the formation of ions in a reactor. Ions are accelerated and separated based on their mass/charge ratio in both procedures, which is utilised to detect explosives.	High, High, Medium, Medium, high, High
		Infrared absorption spectroscopy: The fact that molecule vibrations have distinct wavelengths in the infrared region is used to support this technique. When the molecule's dipole moment changes, resonant light absorption through these vibrations is detected. Large molecules' infrared spectra, on the other hand, might have vast bandwidths, resulting in an unclear spectrum. Furthermore, many explosives disintegrate at the extreme temperatures	Medium, High, Medium, Medium, Medium, Medium
		Opto-acoustic spectroscopy: This method is based on the fact that molecules absorb optical energy, which is then partially converted to thermal energy through relaxation processes. Pressure pulses are recognized by sensitive microphones using pulsed radiation to stimulate the sample, resulting in a photo-acoustic spectrum.	Medium, High, Medium, High, Medium, Low
		Raman scattering: Inelastic light scattering by molecules or atoms is known as Raman scattering. The energy of the vibrational and rotational states can be swapped during the interaction of light with the molecule, resulting in a lower energy quantum of light being released. The Raman effect, on the other hand, is exceedingly weak, with insufficient sensitivity for landmine detection.	Low, High, Low, High, High, Low
		Immuno-chemical Sensor: Proteins that contain the molecule of interest create antigen-antibody complexes. When a drug binds to an antibody, it changes its physical properties, which can be used to identify it.	High, High, Low, Medium, Medium, Medium

Table 2.2 (Continued)

Techniques/ Sub-techniques		Sensor	Complexity, cost, speed, safety, Environmental Effects, False Alarm
Explosive trace Detection	Chemical methods	**Electronic noses:** They are artificial olfactory systems made up of a combination of numerous sensors and pattern recognition algorithms. They put less emphasis on extremely selective sensors and more on the algorithms used to identify the sample. Fluorescent polymers, optical fibre, polymeric films, piezoelectric materials, and micro-electromechanical systems are among the sensors utilised in electronic noses.	High, High, High, Medium, High, Medium
Bulk explosive detection	Neutron analysis methods	**Thermal neutron analysis (TNA):** In TNA, neutrons are emitted, and when they are completely absorbed by a nucleus, gamma rays with energy unique to the nucleus are emitted.	High, High, Low, medium, High, Medium
		Fast neutron analysis (FNA): This method use high-energy neutron to detect and distinguish between distinct types of gamma radiation.	High, High, Medium, Medium, Medium, High
		Pulsed fast neutron analysis (PFNA): Using a pulsed neutron beam, this approach uses the same concept as FNA.	High, High, Medium, Medium, Medium, Medium
		Pulsed fast thermal neutron analysis (PFTNA): PFTNA uses neutron beams that endure a long time. Its key benefits are its excellent durability and mobile design.	Medium, Medium, Low, Medium, Medium, Medium
Nuclear quadrupole resonance (NQR)		This method uses radio frequency pulses to excite nitrogen nucleus in an explosive, causing an electric potential to be generated at a receiver coil.	High, Medium, Medium, Medium, High, Low

Table 2.2 (Continued)

Techniques/ Sub-techniques		**Sensor**	**Complexity, cost, speed, safety, Environmental Effects, False Alarm**
Mine casing detection	Electro-magnetic methods	**Metal detector (MD):** The disturbance of a transmitted electromagnetic field generated by metallic surfaces in the soil is measured by the Meta Detector.	Low, Low, Low, High, Low, High
		Ground penetrating radar (GPR): GPR identifies buried objects by sending radio signals into the surface and thereafter analysing the incoming signals induced by wave reflections at the borders of materials with varying indices of refraction due to changes in electrical characteristics.	Medium, High, Medium, High, Medium, Low
		X-ray backscattering: X-rays are sent into the ground for backscattering. Because of the electron density, different objects having lower atomic number scatter x-ray radiation better, such as plastics.	High, High, low, Low, High, Low
	Mechanical methods	**Electrical impedance tomography (EIT):** EIT allows the visualization of conductivity distribution using a 2-D array of electrode placed on the ground, with mines identified as anomalies.	Low, Medium, Medium, Low, Medium, Medium
		Seismic-acoustic techniques: Acoustic/seismic methods search for mines by "vibrating" them in the ground with seismic waves or sound.	Medium, High, Medium, High, Low, Low
		Ultrasound: The reflected ultrasonic waves from materials with variable acoustic qualities could be used to construct images of hidden interior anatomy.	Medium, Medium, Low, High, medium, High
		Prodding: A trained operator prods the surface with a 25cm long stick at a slight inclination to the ground surface. Today, prodding the ground to confirm the existence of a landmine is generally the only approach to ensure complete detection.	Medium, Low, High, Low, Low, High

Table 2.2 (Continued)

Techniques/ Sub-techniques	Sensor	Complexity, cost, speed, safety, Environmental Effects, False Alarm
Infrared and hyperspectral detection	Milli-meter wave radar (MMWR): It's a hyperspectral system that gathers images at various MMW frequencies with the help of a vector network analyser that collects backscattered MMW radiation from the hidden sample.	High, Medium, Low, High, Medium, Medium
	Infrared cameras (IR): The idea behind utilising infrared thermography to identify mines is that mines can have different thermal characteristics than the surrounding material.	Medium, Medium, High, High, High, Medium
	Laser induced breakdown spectroscopy (LIBS): LIBS generates a micro-plasma at extreme temps using a high-intensity laser, dissolving the substance into atoms and ions. Electron-ion collisions form a continuous spectrum, which can be analysed to identify elements. Different kinds of anti-personnel and anti-tank landmine shells have been identified using LIBS.	Medium, Medium, medium, high, Medium, Low
	Visible light: This method of mine detection uses an optical imaging system to capture visible light wave range.	Low, Low, Medium, High, High, High
	Optical light detection and ranging (LIDAR): After lighting a surface with linearly polarised light, LIDAR detects polarisation variations in the back-scattered light. Due to their smooth texture in comparison to the rough background, landmines on the surface of the ground can be noticed.	High, High, Medium, High, Low, Medium
	Vibration-Enhanced Underground Sensing (VENUS) system: An electromagnetic stimulation is used to produce mechanical vibrations in underground targets, which can then be detected using just a sensitive RF vibrometer.	Medium, High, High, Medium, Medium, Medium
	Spectroscopic: Analyses the sample's spectral response and validates the presence of explosives.	Medium, High, Medium, Medium, Medium, Low

From the previous table we concluded that there is no single mine detecting system that can detect all types of mines in all situations. Nuclear quadrupole resonance, for example, can swiftly locate mines containing the explosive cyclotrimethylene-nitramine (also known as royal demolition explosive [RDX]), but it takes longer to confirm the presence of trinitrotoluene (TNT). Although acoustic mine detection devices have low false alarm rates, they cannot detect mines buried at depths greater than one landmine diameter. [29].

2.4 MINE COUNTER MEASURES

Mine counter measures refer to any activity taken to neutralise, destroy, disrupt, or render a mine inactive. MCM, sometimes known as de-mining, is usually broken down into three stages: detection, removal, and disposal. A complete survey of minefields, the nature of topography, and the types and number of minefields in each site (if known) must all be determined before an MCM operation can begin. A reasonable plan of action can be framed based on this knowledge [26].

Figure 2.5: Humanity & Inclusion (HI) deminer at work [24]

Landmine detection systems usually follow one of two paths: (i) When a landmine is buried beneath the ground, it disturbs the surrounding and overlaying dirt. The change in soil properties can then be utilised to identify buried landmines; (ii) buried landmines have different qualities (density, strength, thermal capabilities, etc.) than the surrounding soil. Various methods can be used to detect these property changes. Hand-prodding, brute-force, hi-tech, and biological detection strategies are the current mine detecting methods. Because the bulk of modern mines have very little or no metal components, metal detection is no longer a reliable method of detection [25].

CHAPTER 3

REVIEW OF TERRAIN IMPLICATIONS ON SUB-SURFACE OBJECTS AND LANDMINE DETECTION

3.1 TERRAIN IMPLICATIONS

3.1.1 Physical Geography of India and Terrain

India has a wide range of physical characteristics. The Peninsular Plateau is one of the oldest landmasses on the planet, according to geology. One of most stable land blocks was expected to be this one. The most recent landforms are the Himalayas and the Northern Plains. The Himalayan mountains represent an unstable zone from a geological standpoint. With towering peaks, deep valleys, and fast-flowing rivers, the Himalayan Mountain chain as a whole displays a relatively youthful topography. Alluvial sediments make up the northern plains. With slowly rising hills and vast valleys, the peninsular plateau is made up of igneous and metamorphic materials [35].

3.1.2 Primary Physiographic Divisions

India's physical characteristics can be classified into the following physiographic divisions and are shown in figure 3.1:

- **I.** The Himalayan Mountains
- **II.** The Northern Plains
- **III.** The Peninsular Plateau
- **IV.** The Indian Desert
- **V.** The Coastal Plains
- **VI.** The Islands

3.1.2.1 The Himalayan Mountains

The Himalayas, geologically young and structurally fold mountains that reach beyond India's northern boundaries, are geologically young and structurally fold mountains. From the Indus to the Brahmaputra, these mountain ranges run west to east. The Himalayas are the world's tallest and most treacherous mountain ranges. They create an arc that spans around 2,400 kilometres. They range in width from 400 kilometres in Kashmir to 150 kilometres in Arunachal Pradesh. In the eastern part, the altitudinal fluctuations are higher than in the western half. In terms of length, the Himalaya is divided into three parallel ranges. Between these two ranges are a multitude of valleys. The Great or Inner Himalayas, also known as the Himadri, are the highest mountain range in the world. It is the longest range in the world, with the highest peaks averaging 6,000 metres in height. It encompasses all of the major Himalayan summits. The Great Himalayan folds are naturally asymmetrical. Granite dominates this section of the Himalayas. It is snow-bound all year, and a number of glaciers flow down from it [36].

The Himachal, or smaller Himalaya, range lies to the south of the Himadri and forms the most rocky mountains system. The majority of the ranges are made up of heavily crushed and deformed rocks. The altitude ranges from 3,700 to 4,500 metres, with an average breadth of 50 kilometres. The Pir Panjal range is the longest and most important range, but the Dhaula Dhar and Mahabharat ranges are also significant. In Himachal Pradesh, this range includes the famed Kashmir Valley, the Kangra Valley, and the Kullu Valley. The hill stations of this region are well-known [35].

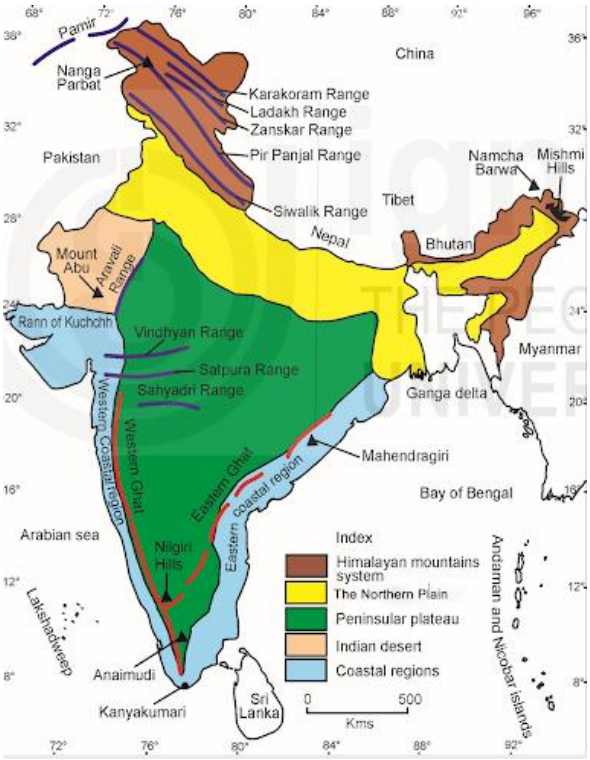


Figure 3.1: Physiographic Division of India [35]

The Shiwaliks are the Himalayan range's furthest reaches. They have a breadth of 10 to 50 kilometres and an elevation of 900 to 1100 metres. These mountains are made up of unconsolidated sediments that have been washed down from the main Himalayan ranges to the north. Gravel and alluvium blanket these valleys. Duns are the longitudinal valleys that run between the lower Himalaya and the Shiwaliks. Some of the well-known Duns include Dehra Dun, Kotli Dun, and Patli Dun [37].

The Himalayas have also been classified into areas from west to east, in addition to longitudinal divides. River valleys have marked the boundaries of these divisions. The Himalayan region between the Indus and the Satluj, for example, has been known as Punjab Himalaya in the past, but it is currently recognised regionally as Kashmir and Himachal Himalaya, respectively, from west to east. The Kumaon Himalayas are located between the Satluj and Kali rivers in the Himalayas. The Nepal Himalayas is defined by the Kali and Teesta rivers, whereas the Assam Himalayas are defined by the Teesta and Dihang rivers [38].

3.1.2.2 Northern Plains

The Indus, Ganga, and Brahmaputra, as well as their tributaries, have shaped the northern plain. Alluvial soil has created this plain. This rich plain was developed millions of years ago by alluvium deposition in a huge basin in the foothills of the Himalaya. It has a 7-lakh square kilometre area. The plain, which stretches for around 2400 kilometres and is 240 to 320 kilometres wide, is a highly inhabited physiographic division. It is an agriculturally productive portion of India, with a rich soil cover, enough water supply, and a favourable climate. Depositional work is carried out by rivers flowing from the northern ranges. The river's velocity diminishes in the lower course due to the mild slope, resulting in the construction of riverine islands [2].

The Northern Plain is separated into three sections in general. The Punjab Plains are the westernmost section of the Northern Plain. The Indus and its tributaries carved out the majority of this plain, which is mostly in Pakistan. In the Himalaya, the Indus and its tributaries, the Jhelum, Chenab, Ravi, Beas, and Satluj, begin. The doabs are in charge of this area of the plain [37].

The northern plains are often thought of being flat territory with no relief fluctuations. The relief features on these huge plains are likewise varied. The Northern Plains can indeed be separated into four regions based on differences in relief features. The rivers drop gravel in a narrow area of roughly 8 to 16 kilometres in width that runs parallel to the Shiwaliks' slopes after they descend from the mountains. It's called bhabar. In the bhabar belt, all streams disappear. The rivers and streams resurface south of this region, forming the terai, a damp, swampy, and marshy environment. This was a densely forested area teeming with wildlife. The trees have been destroyed to make way for farmland and to house [39].

3.1.2.3 The Peninsular Plateau

The Peninsular plateau is made up of ancient crystalline, igneous, and metamorphic materials. It was developed as a result of the Gondwana continent fracturing and drifting, making it the oldest landmass on the planet. Broad and shallow valleys, as well as rounded hills, can be seen on the plateau. The Central Highlands and Deccan Plateau are the two major divisions of this plateau. The Central Highlands span a large region of the Malwa plateau and are located towards the north of the Narmada River on the Peninsular peninsula. The Satpura range to the south and the Aravalis to the northwest encircle the Vindhyan range [36]. The desert of Rajasthan progressively mixes with the farther westward stretch. The flow of the rivers that drain this region, such as the Chambal, Sind, Betwa, and Ken, flows from southwest to northeast, indicating the slope. In the west, the Central Highlands are wider, whereas in the east, they are narrower. The Bundelkhand and Baghelkhand are local names for the plateau's eastward extensions. The Damodar River drains the Chotanagpur plateau, which defines the further eastward extension [38].

The Deccan Plateau is a triangular plateau lying south of the Narmada River. In the north, the Satpura range runs parallel to its broad base, while the Mahadev, Kaimur Hills, and Maikal range run parallel to it in the east. The Deccan Plateau rises in the west and gently dips east. A northeastern extension of the Plateau, called locally as the Meghalaya, Karbi-Anglong Plateau, and North Cachar Hills, may also be seen. A fault separates it from the Chotanagpur Plateau. The Garo, Khasi, and Jaintia Hills are three prominent hill ranges that go from west to east [35].

The black soil region called Decean Trap is one of the Peninsular plateau's most distinctive features. Because the rocks are igneous, they are of volcanic origin. In fact, these rocks have depleted through time, resulting in the creation of black soil. The Aravali Hills are located on the Peninsular plateau's western and northern edges. These are fractured hills that have been heavily eroded. They run in a southwest-northeast direction from Gujarat to Delhi [37].

3.1.2.4 The Indian Desert

The Aravali Hills' western edges are home to the Indian desert. It's a sand-dunes-covered undulating sandy plain. The average annual rainfall in this area is less than 150 mm. It has a dry climate with little vegetation. During the wet season, streams appear. They vanish into the sand soon after because they don't have enough water to make it to the sea. The Luni River is the only major river in the area. Longitudinal dunes are more common near the Indo-Pakistan border than barchans (crescent-shaped dunes) [35].

3.1.2.5 The Coastal Plains

The Arabian Sea to the west and the Bay of Bengal to the east edge the Peninsular plateau. The western shore is a narrow plain situated between the Western Ghats and the Arabian Sea. It is divided into three pieces. The northern half of the coast is known as the Konkan (Mumbai – Goa), while the central stretch is known as the Kannad Plain and the southern stretch as the Malabar coast [38].

The plains that run parallel to the Bay of Bengal are broad and level. It's called the Northern Circar in the north and the Coromandel Coast in the south. On this shore, large rivers like the Mahanadi, Godavari, Krishna, and Kaveri have built huge deltas. Along the eastern coast, Lake Chilika is a significant landmark [37].

3.1.2.6 The Islands

The Lakshadweep Islands are a group of islands near Kerala's Malabar coast. Small coral islands make up this group of islands. They used to be called Laccadive, Minicoy, and Amindive. Lakshadweep was given to them in 1973. It is only 32 square kilometres in size. Lakshadweep's administrative headquarters are on the island of Kavaratti. The vegetation and wildlife of this island group are extremely diverse. A bird sanctuary is located on the isolated Pitti island. [35]

The Andaman and Nicobar Islands are a lengthy series of islands in the Bay of Bengal that stretches from north to south. They are larger, more numerous, and more widely dispersed. The Andaman Islands in the north and the Nicobar Islands in the south make up the complete group of islands. These islands are thought to represent raised portions of undersea mountains. The country's strategic importance depends on these island groups. This archipelago of islands also has a wide range of vegetation and animals.

These islands are close to the equator, have an equatorial climate, and are densely forested [39].

3.2 ISSUES AND IMPLICATIONS OF TERRAIN

Landmines are increasingly being used offensively, despite the fact that they were designed primarily as defensive weapons. Table 3.1 shows the issues and implications of physical geography and terrain of India.

Table 3.1 Terrain Implications

<table>
<tr><th>Terrain/ Geography Type</th><th>LU/LC</th><th colspan="2">Implications</th></tr>
<tr><td rowspan="9">Mountains</td><td rowspan="3">Snow/ Glaciers/ Rivers</td><td>Mining</td><td>Mining is easy but weather conditions are not suitable for the working of landmines.</td></tr>
<tr><td>Monitoring</td><td>Challenging task to monitor mines during heavy snowfall.</td></tr>
<tr><td>Demining</td><td>When snow melts, mines dislocate, and hence demining becomes difficult.</td></tr>
<tr><td rowspan="3">Rocks</td><td>Mining</td><td>Deployment of mines is difficult in rocks due to the hard surface of rocks.</td></tr>
<tr><td>Monitoring</td><td>Monitoring is uncomplicated.</td></tr>
<tr><td>Deming</td><td>Once deployed, demining is quite difficult in rocky region.</td></tr>
<tr><td rowspan="3">Forest Cover</td><td>Mining</td><td>Mining is trouble-free in vegetation.</td></tr>
<tr><td>Monitoring</td><td>Easily monitored as area is accessible and can easily locate them.</td></tr>
<tr><td>Demining</td><td>Demining is relatively easy but contaminates the soil and vegetation.</td></tr>
<tr><td rowspan="7">Northern Plains</td><td rowspan="3">Forest Cover</td><td>Mining</td><td>Mining is trouble-free in forest</td></tr>
<tr><td>Monitoring</td><td>Easily monitored as area is accessible and can easily locate them.</td></tr>
<tr><td>Demining</td><td>Demining is relatively easy but contaminates the soil and vegetation.</td></tr>
<tr><td rowspan="3">Built-up Area</td><td>Mining</td><td>Mining is easy but affect the locals.</td></tr>
<tr><td>Monitoring</td><td>Monitoring is trouble-free but interference of residents will be there.</td></tr>
<tr><td>Demining</td><td>Demining is less-challenging.</td></tr>
<tr><td>Water Bodies</td><td>Mining</td><td>Mines can be placed by aircraft, or individual swimmers and boatmen.</td></tr>
</table>

Table 3.1 (Continued)

Terrain/ Geography Type	LU/LC	Implications	
Northern Plains	Water Bodies	Monitoring	Monitoring is difficult due to currents or flow of water bodies.
		Demining	The task is quite challenging due to the continuous flow of water.
	Agricultural Land	Mining	Mining is trouble-free in vegetation.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is relatively easy but contaminates the soil and vegetation.
	Barren Land	Mining	Mining is trouble-free.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is comparative easier.
Plateau	Forest Cover	Mining	Mining is trouble-free in vegetation.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is comparative easier but contaminates the soil and vegetation.
	Built-up Area	Mining	Mining is easy but affect the locals
		Monitoring	Monitoring is trouble-free but interference of residents will be there.
		Demining	Demining is less-challenging.
	Water Bodies	Mining	Mines can be deployed but high explosive required.
		Monitoring	Monitoring is difficult due to currents or flow of water bodies.
		Demining	The task is quite challenging due to the continuous flow of water.
	Rocks/ Barren land	Mining	Deployment of mines is difficult in rocks due to the hard surface of rocks.
		Monitoring	Monitoring is uncomplicated.
		Demining	Once deployed, demining is quite difficult in rocky region.
	Agricultural Land	Mining	Mining is trouble-free in vegetation.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is comparative easier but contaminates the soil and vegetation

Table 3.1 (Continued)

Terrain/ Geography Type	**LU/LC**	**Implications**	
Desert	Bare Sand Land	Mining	Deployment is easy.
		Monitoring	Monitoring becomes difficult sometimes due to sand dunes.
		Demining	Demining is comparative easy once monitored.
	Built-up Area	Mining	Mining is easy but affect the locals
		Monitoring	Monitoring is trouble-free but interference of residents will be there.
		Demining	Demining is less-challenging.
Coastal Plains	Forest cover (mangroves)	Mining	Mining is difficult due to marshy land.
		Monitoring	Monitoring is easy.
		Demining	Demining is manageable.
	Agricultural land	Mining	Mining is trouble-free in vegetation.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is relatively easy but contaminates the soil and vegetation.
	Built-up area	Mining	Mining is easy but affect the locals.
		Monitoring	Monitoring is trouble-free but interference of residents will be there.
		Demining	Demining is less-challenging.
	Water Bodies	Mining	Mines can be deployed by aircraft, or individual swimmers and boatmen.
		Monitoring	Monitoring is difficult due to currents or flow of water bodies.
		Demining	The task is quite challenging due to the continuous flow of water.
Island	Forest Area	Mining	Mining is trouble-free in vegetation
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is comparative easier but contaminates the soil and vegetation.
	Built-up Area	Mining	Mining is easy but affect the locals.
		Monitoring	Monitoring is trouble-free but interference of residents will be there.
		Demining	Demining is less-challenging.

Table 3.1 (Continued)

Terrain/ Geography Type	LU/LC	Implications	
Island	Water Bodies	Mining	Mines can be deployed easily by ships, submarines, or individual swimmers and boatmen but high explosive required.
		Monitoring	Monitoring is difficult due to currents or flow of water bodies.
		Demining	The task is quite challenging due to the continuous flow of water.
	Barren Land	Mining	Mining is trouble-free.
		Monitoring	Easily monitored as area is accessible and can easily locate them.
		Demining	Demining is comparative easier.

CHAPTER 4

SUBSURFACE OBJECT AND LANDMINE DETECTION USING SCATTEROMETER

4.1 INTRODUCTION TO THE PROBLEM

Landmines continue to represent a major threat to both military and civilians. These weapons can be spotted on roadways, footpaths, farms, woodlands, desert, along borders, in and around residences and schools, and other locations where people go about their everyday lives. They restrict access to healthy food, water, as well as other essential necessities, as well as mobility. They jeopardise the original flight, prohibit refugees and internally displaced persons from returning home, and obstruct humanitarian aid delivery [40].

These weapons instil dread in communities whose residents are often aware that they are passing through mined areas but have no other options for farming or getting to school. When land cannot be cultivated, medical systems are drained by the cost of treating landmine casualties, and countries must spend money clearing mines rather than paying for education, it is evident that these weapons not only cause horrific human misery, but also act as a lethal impediment to the implementation of the Sustainable Development Goals (SDGs) and post-conflict reconstruction [24].

The fundamental demining procedure entails physically poking the dirt to detect the mine and then removing it, which is quite dangerous. The risk is being reduced by using electromagnetic (EM) imaging technology that generates backscatter data from the suspected zone and processes it simultaneously to detect the presence of landmines. This method is demonstrated by Landor vehicle-based Ground Penetrating Radars (GPRs). Landmine detection and removal is challenged by the range of mine types, soils, scattering from layered media, vegetation, and other factors [12].

The dielectric contrast among various intermediary mediums such as air, heterogeneous nature of soil, and the mine is used in most detection procedures. Landmines are frequently buried flush with the surface or at modest depths, and contain little or no metal. As a result, the dielectric contrast between the stratified soil medium and the landmine overlaps with the dielectric contrast at the air-ground surface, lowering the mine's backscatter response and making identification extremely difficult. In order to detect small shallow buried landmines that contain little or no metal, two key obstacles must be overcome: soil clutter reduction and mine feature extraction. Furthermore, because minefields are frequently laid out over a vast region, the utility of surface or vehicle-based approaches for landmine detection may be limited [34].

4.2 EXPERIMENTAL SETUP

4.2.1 Scatterometer System

Scatterometers are used to determine the received power of surface backscattering reflected from an object's surface. According to a precise interpretation, a microwave scatterometer is a space-based sensor that measures the two-dimensional velocity components of the sea wind, but a broader definition includes airborne sensors as well as ground-based sensors that measure surface backscattering and volume scattering, such as rain radar [41].

All of the experiments in this study employed an indigenously designed monostatic scatterometer at X-band. The scatterometer comprises of a transmitter, receiver, antenna, and data processing and recording electronics. The transmitter sends out brief bursts (or microwave pulses) at regular intervals, which the antenna focuses into a beam directed at the target. The surface is illuminated by the radar beam. A part of the transmitted energy is reflected (or backscattered) by various objects inside the lighted beam, which is received by the antenna. An image of the ground can be created by measuring backscattered "echo" from different targets. A monostatic scatterometer is one that uses a single antenna and a circulator for both transmitting and receiving microwave signals [12].

An antenna is a device that converts high-frequency electric current into radio waves and back. To send and receive radio waves, an antenna is used. There are numerous different types of antennas, ranging in size from very small (like micro antenna in a wireless phone) to very enormous (100 metre diameter) antenna reflectors for radio signal astronomy. Passive microwave radiometer antennas, active microwave altimeter antennas, scatterometer antennas, and imaging radar antennas are all used in microwave remote sensing. Horn antennas, reflector mirror antennas, and array antennas are the three main types of antennas. The horn antenna, such as the conical or rectangular horn, is used for power supply to the reflector antenna, low temperature calibration and active radar calibration. A main radiator and a reflected mirror make up a reflector antenna like a parabolic or Cassegrainian antenna. Microwave radiometers, altimeters, and scatterometers all use the reflector antenna. Multiple element arrays, such as a linear array, area array, or non-formal array, make up an array antenna. Half-wavelength dipoles, microstrip patches, and wave guide slots are the element antennas. The advantages of array antennas include beam scanning without changing the viewing angle of each array antenna and beam shaping through selective excitation of each element's current distribution. Synthetic aperture radar (SAR) and real aperture radar both use the array antenna.

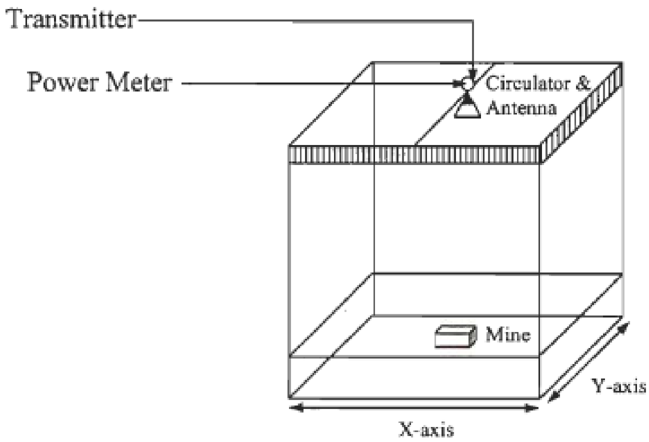


Figure 4.1: Scatterometer System

A variety of experiments were carried out with dummy landmines buried in sand without explosives for detection. The studies were carried out with a monostatic scatterometer that was created in-house. Figure 4.1 depicts the schematic arrangement of an indigenously built monostatic scatterometer system. On one side, a circulator connects a pyramidal horn antenna to a microwave transmitter, while on the other, a power metre. In both HH and VV polarizations, an isolator with a 35 dB isolation was employed to generate experimental data. Mines will be buried in a wooden box that measures 120×120 cm and is filled with dry sand. The base of the X-band antennae is 100 cm above the surface. The antennae can be moved in both X and Y directions by the system. To build a grid, the horizontal bars on both sides (referred to as X-Y direction) were marked serially in 5 cm steps from 1 to 24. For data collection, the circulator and antenna are moved laterally (Y-direction) from 1 to 24 at each of the horizontal (X-direction) places from 1 to 24, total 24×24 positions.

4.2.2 Design of Experiment

The scatterometer generates energy in the form of an electromagnetic (EM) wave, which follows the fundamentals of wave theory and behaves predictably. An electric field (E) varying in magnitude in a perpendicular direction to the wave's travel direction, and a magnetic field (M) orientated at perpendicularly to the electric field, make up an electromagnetic wave as shown in Figure 4.2.

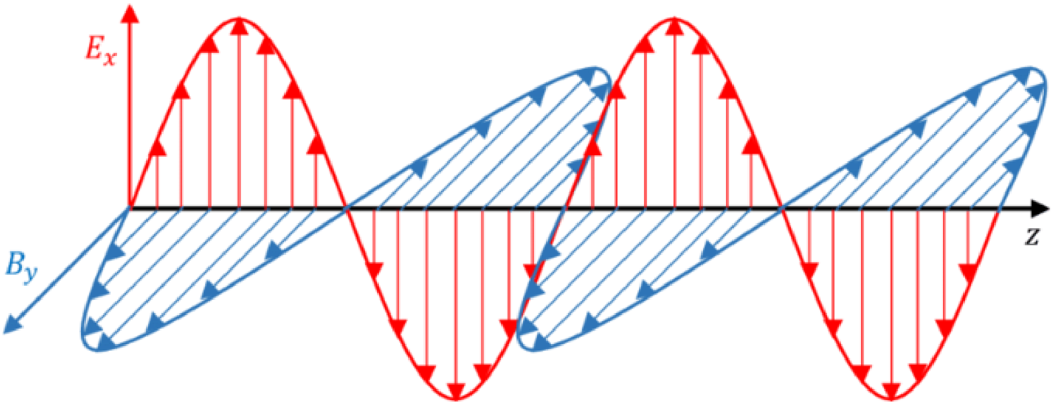


Figure 4.2: Electromagnetic Wave [14]

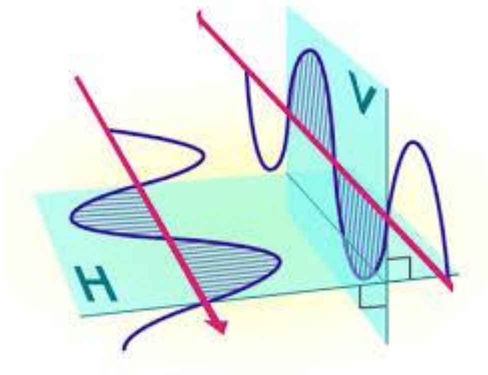


Figure 4.3: HH and VV Polarisation [14]

While addressing microwave energy radiation, polarisation, or the orientation of the electric field, is a crucial consideration. Scatterometer are frequently built to transmit either horizontally polarised (H) or vertically polarised (V) microwave radiation shown in Figure 4.3. The orientation of the E-plane in horizontal polarisation is horizontal to the EM wave propagation direction in reference to the ground, whereas it is vertical in vertical polarisation. A twister is attached to the antenna in order to alter the E-plane in the case of a scatterometer. The generated EM wave may have either polarisation following interaction with the object/target. As a result, the antenna receives backscattered energy that is either horizontally or vertically polarised. The letters 'H' for Horizontal and 'V' for Vertical are commonly used to denote these two polarisation states. Only two transmit and receive polarisation combinations, HH (horizontal transmit and horizontal receive) and VV (vertical transmit and vertical receive), were evaluated in this study.

Because of the contradiction between the necessity for surface penetration and tolerable ground resolution, frequency selection is a key element in microwave radar remote sensing for detecting buried landmines/objects. Lower frequencies penetrate more deeply, while higher frequencies resolve more effectively. Microwave X-band at 10 GHz, 3 cm may provide enough penetration and surface resolution when landmines are planted flush with the ground at shallow depths.

Backscatter energy at the sensor is determined by the way EM waves interact with the soil surface. Because the wavelength in the X- Band is in the range of 3cm, certain surfaces may appear rough; as a result, the experiment has been divided into two parts: smooth and rough surface. The investigations in this study are conducted on 'smooth' surface. Further, because the sizes of non-homogeneous particles and the distance between them are of the order of 2.5×10^{-3}, both of which are significantly less than the wavelength, volumetric scattering from non-homogeneities of layered media (rough surfaces like in sand layer) can be neglected at this band. As a result, all of the trials in this work were carried out in the microwave X band with dummy landmines hidden in dry sand with smooth surface roughness conditions. For different mines dug at varying depths, experimental data were collected in HH and VV polarisation. The raw data was then processed using the proposed model for depth detection and estimate.

A dummy Antitank Landmine with no explosion was used in two independent sets of testing. Table4.1 shows the Landmine in detail. The first set of trials were carried out in a laboratory setting with a dummy landmine. Both of the experiments in this set were carried out in dry sand with a smooth surface.

The amount of backscatter accessible at the scatterometer end is largely determined by the surface roughness of a feature, which controls how microwave energy interacts with the target surface. Surface roughness is measured in centimetres and refers to the average height variability in the surface cover from a plane surface

Table 4.1: Details of mines used in experiment [22]

Landmine		**Dummy Antitank Landmine**	**Live Antitank Landmine**
Image			
Dimensions	**Weight**	7 kg	7 kg
	Height	7 cm	7 cm
	Width	25 cm	25 cm
	Length	25 cm	25 cm

The wavelength of an EM wave is used to define surface roughness. If the height deviations on a surface are substantially smaller than the wavelength, it is regarded "smooth," while otherwise, it is considered "rough”. A surface is termed as smooth mathematically if its roughness is less than the value provided by-

$$h < \frac{\lambda}{25 \times Sin\propto} \quad 4.1$$

where $h =$ surface roughness

$\lambda =$ wavelength

$\propto$ = grazing angle i.e angle w.r.t incident surface plane (here $\propto = \pi/2$ is of less than 0.12cm for smooth surfaces)

The second set of tests was carried out in the open in natural light. Furthermore, whereas laboratory studies were carried out with smooth surface roughness, field investigations were carried out with both smooth and rough surface roughness. Experiments with smooth surface roughness are the focus of the investigation. The media in which the mines were buried in both sets of trials was dry sand. Backscatter was measured in both HH and VV polarisation at all of the 24×24 sites in each case, with the mines buried in the centre. These dummy landmines with no explosives are thought to have a dielectric constant of 4-10. Smooth dry sand's dielectric constant has been estimated to be in the range of 3-5. The table below summarises the entire experimental design.

4.3 THEORETICAL MODELLING

The dielectric characteristics of the intermediate interacting mediums determine the backscattered electrical field of microwave. High soil clutter and attenuation of desirable backscatter signals from the landmine surface come from the existence of higher dielectric contrast at the soil-air interface compared to low dielectric contrast at the soil-mine interface.

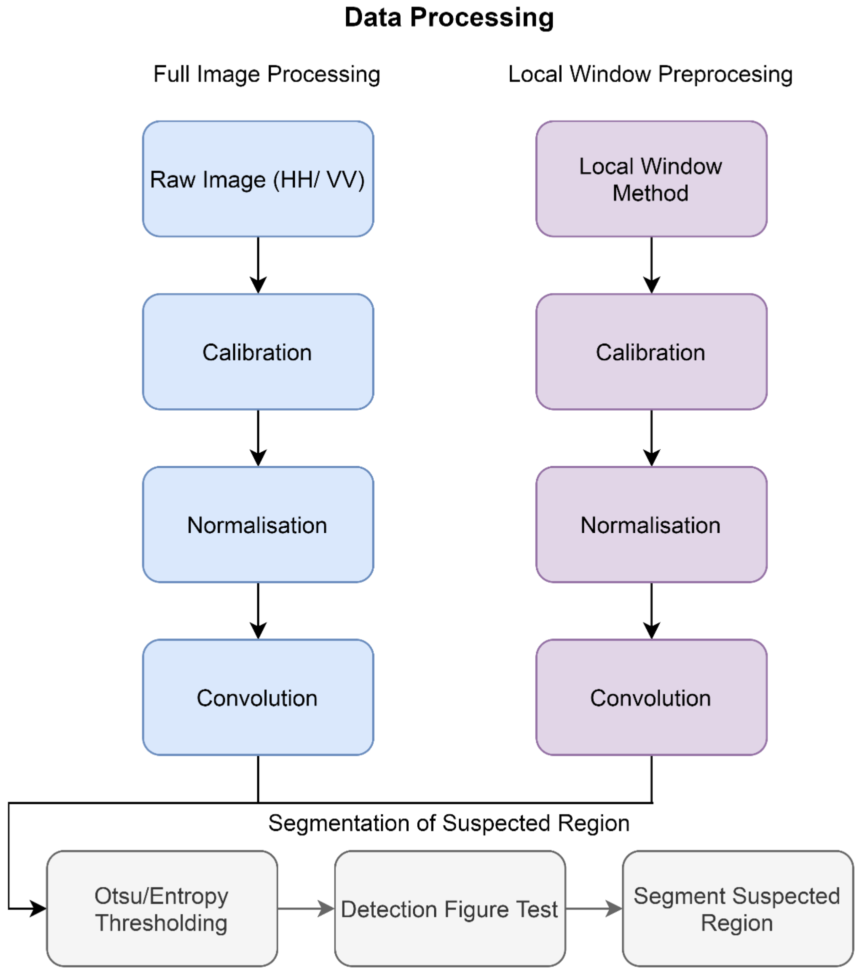


Figure 4.4: Flow Chart for Implementation of Model

In order to improve the target signal, all types of unwanted signals must be estimated and then removed. Simple computation of the mean vector and subtraction of this value from pixel grey readings is a common approach for clutter removal. This strategy, however, fails if the ground surface contour is not smooth. The goal of extracting the features of mine is to classify a signal into mine or non-mine characteristics, make a post-processing choice between the two, and extraction of features containing the landmine. A series of actions have been examined in the current model for segmenting and masking a putative zone of interest that included the mine. In the next paragraphs, these steps are explained in detail and flow chart for the same is shown in Figure 4.4.

4.3.1 Step 1: Data Processing

The raw data was created in a 2424 matrix grid. Each pixel was considered to be one grid of the 24×24 array. The raw backscatter measurement was calibrated with an aluminium sheet that has a conductivity of 3.5×10^7 Seimens per metre and is believed to be an ideal reflector (reflectivity coefficient 1). Inside the sandpit, an aluminium sheet having same dimensions of the sandpit was installed, and backscatter readings for the entire 24×24 array were recorded. Backscatter data with buried minefields at various depths were split pixel by pixel by the matching aluminium sheet readings. The raw image was calibrated and then normalised using the equation below:

$$I_{normalised} = \frac{I_{observed} - I_{min}}{I_{max} - I_{min}} \quad 4.2$$

where I_{max} and I_{min} are the maximum and minimum values in the observed data, respectively.

$I_{observed}$ is the backscattered intensity at a specific location. To put all of the data in one place, normalisation was performed range. The antenna system's lighting area is not restricted to because of the image's pixel size, there is a considerable contribution from pixels in the immediate vicinity. As a result, to reduce the effect of overlap of to decrease the influence of the scattered field from surrounding pixels. An improved 5×5 convolution kernel filter was developed to deal with random noise spikes. It should be noted, however, that the antenna and microwave frequency range chosen will determine which convolution filter is optimal.

For data pre-processing, two approaches were considered: full image data pre-processing and local window data pre-processing, both of which are discussed below:

1. **Full image Data Pre-processing:** In this approach, the entire raw image generated during the experiments is treated to the above-mentioned sequence of data pre-processing procedures without being subjected to any further image processing task. This method has the advantage that it allows study of the real raw backscatter image. This strategy, however, may result in the loss of mine features in the case of

underground landmines when the backscatter from the mine may not show any substantial deviation from the surroundings.

2. **Local Window Data Pre-processing:** In a heterogeneous background, mine feature extraction necessitates distinguishing between mine-like and non-mine-like features. The backscatter response from a minefield in a scatterometer measurement is usually confined to a small number of pixels due to limited dielectric differences between the landmine and the medium in which it is buried, clutter deriving from dielectric contrast at multiple medium interfaces, clutter due to surface roughness, and the tiny size of the landmine. Processing in a local window is more useful in these scenarios to identify pixels with mine-like properties. The procedure is as follows:
   (a) First, a new image is created by multiplying an identity matrix of the similar size as the raw image with the raw image's mean backscatter value. A flat image with a height equal to the mean backscatter value is a three-dimensional plot of this image. Furthermore, because the backscatter from the landmine may be less than this mean backscatter, the new image is scaled down by a fraction within the range of 0.5 to 0.8, the precise value of which is calculated by trial and error in each experiment.
   (b) The image data is then subdivided into many blocks of smaller windows, each of which is transferred to its corresponding place in the new image and processed through the various data preparation stages detailed above. The appropriate window size is determined by the mine's predicted size, resolution, the existence of other objects in the immediate vicinity, and clutter. In this scenario, an 8×8 pixel window was deemed adequate; nevertheless, larger window widths should be preferred because they may speed up processing.

4.3.2 Step2: Extraction of mine feature

Mine feature extraction entails segmenting a landmine-infested area and performing a test to eliminate false alerts. Thresholding is a popular approach for segmenting a picture to find the probable area where an object might be concealed due to its ease of implementation. However, choosing the right threshold value is crucial to detecting an object accurately. Two thresholding strategies for extracting mine features which are Otsu's and entropy based were used to extract mine features from the complicated data obtained for each of the mines at different depths. Here is a quick rundown of the two thresholding methods. The two thresholding approaches are briefly explained below:

(a) Otsu's method: Otsu's method includes a mechanism for setting a threshold in order to make each cluster as close together as possible. Its goal is to reduce within-class variance while increasing between-class variation. The normalised histogram can be understood as a discrete probability density function in this histogram-based strategy, given-

$$p_r(r_q) = \frac{n_q}{n} \qquad 4.3$$

where $q = 0, 1, 2 \ldots L-1$, n is the total number of pixels in the image, n_q is the number of pixels that have intensity level r_q, and L is the total number of possible intensity levels in the image. When a threshold is chosen to divide an image into two components, Otsu's approach selects the threshold that minimises within-class variation while maximising between-class variance.

(b) Maximum entropy principle (Shannon entropy): When there is little or no information, the maximum entropy principle is used to choose a priori probability distributions. It asserts that the probability distribution that best captures our knowledge for a given quantity of information is the one that maximises the 'Shannon entropy' subject to the evidence provided as constraints. A bi-level image is produced after using threshold t to threshold an image. Equation gives a posteriori probability of pixels having grey values less than the threshold.

$$F(t) = \sum_{i=0}^{t} p_i \qquad 4.4$$

Similarly, for all pixels with values larger than or equal to t, the a posteriori probability is $(1 - F(t))$. As a result, equation 4.5 gives the Shannon entropy of the bi-level image

$$H(F(t) = -F(t)logF(t) - \big(1 - F(t)\big)\log(1 - F(t)) \qquad 4.5$$

If nothing else is known, the Shannon entropy of the bi-level image is maximised to find an optimal threshold. However, the image's histogram may not always be bi-modal, and additional information about the image, such as uniformity or shape measures, may need to be included.

4.4 DETECTION FIGURE TEST

Any detecting system must be reliable enough to generate as few false alerts as possible. To forecast detections that are sensitive to noise and background light, appropriate detection accuracy measures must be incorporated. A quantitative detection figure (D) test based on picture statistics has been designed to evaluate the correctness of detection and reduce false points. The detection figure test is performed on threshold data and is based on the intensity value of foreground pixels (those pixels with a reading greater than or equal to the threshold) and the mean intensity of the entire data. The detection figure (D) is described as follows:

$$Detection\ figure\ (D) = \frac{A(FG) - A(BG) \times 100}{A(FG + BG)} \qquad 4.6$$

Where, $A(FG)$ = mean reading for foreground pixel, $A(BG) =$ mean reading for background pixels and $A(FG + BG) =$ mean reading for all pixel

The detection figure was calculated for various dummy landmine depths. When there is no object buried in the sandpit, all readings are backscattering from the sand, therefore the difference between $A(FG)$ and $A(BG)$ is minimal, and the detection figure is small. It was observed that if the detection figure generated is much less than 40, there is no object buried in the ground. For correct detections, however, detection figure values were obtained in the range of $40\ to\ 80$.

CHAPTER 5

RESULTS AND DISCUSSIONS

Dummy landmine without explosives (dummy antitank) was tested at different depths in the lab. The data was collected at ten different depths ranging from 0.5 cm to 10 cm in HH and VV polarizations. Because the pattern of results for dummy mine at varying depths is nearly identical, and are discussed in this section.

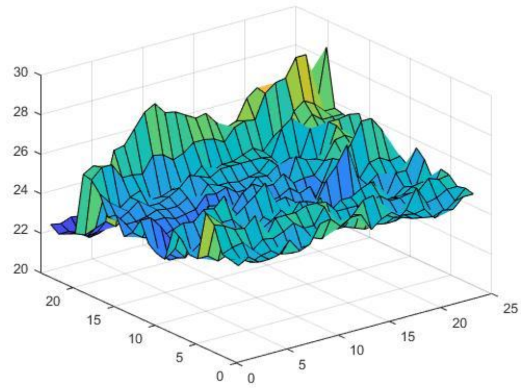
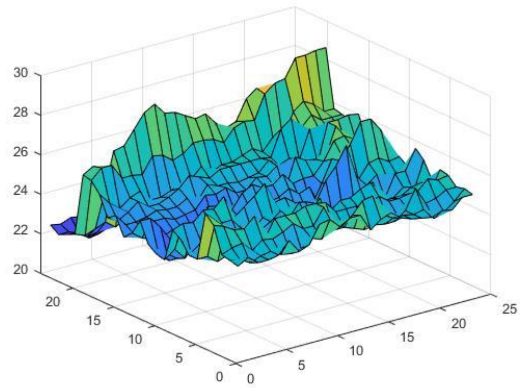
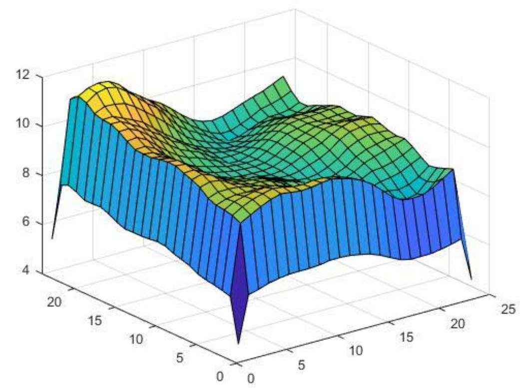
5.1 EFFECT OF DATA PRE-PROCESSING

5.1.1 Full Image Data Pre-processing

Full image data pre-processing and local window-based data pre-processing were used for data pre-processing. Because full image data pre-processing preserves the properties of the original data, the raw data collected in the lab for dummy mine at varied depths was first processed using several data pre-processing procedures, including calibration, normalization, and convolution.

Table 5.1 shows the graphs for raw data, calibrated data, and convoluted data for an antitank mine at a depth of 1 cm. The results are identical at all depths, including for the active antitank mine. The objective of data pre-processing is to process the image to the point where it is possible to extract required attributes from it. Due to clutter from numerous sources, particularly that from the corners of boxes, the plots for the raw data are highly unpredictable. Figure 5.1 (b) depicts data preparation after calibration, whereas Figure 5.1 (c) depicts data pre-processing after convolution. Data pre-processing in this way produces a smoothed image with minimal noise around the edges. There is a tiny dip in all of the convoluted plots towards the centre. As a result, the convolution image for all the mines at all depths emphasized the probable area containing the mines, which was kept at the centre in these studies. A similar pattern can be seen at all other depths.

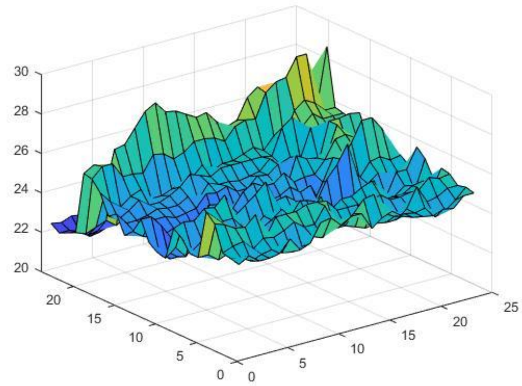
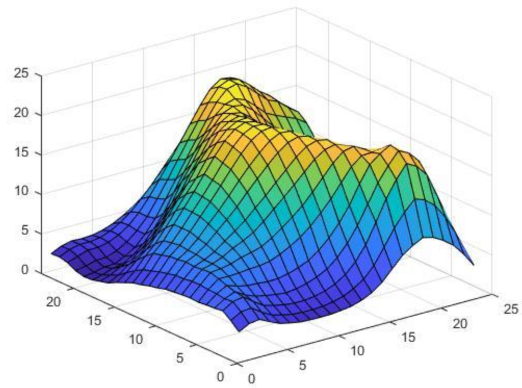
Table 5.1: Graphs for Raw Data, Calibrated Data, and Convoluted Data for an Antitank Mine at a Depth of 1 cm

Data Processing Stages	**Dummy Anti-Tank Mine**
Raw Data	 Figure 5.1 (a)
Calibrated Data	 Figure 5.1 (b)
Convoluted Data	 Figure 5.1 (c)

5.2.1 Effect of Local Window based Data Pre-processing

In the presence of clutter, the dielectric variations caused by mine are likely to be observed in only a few pixels. The goal of data pre-treatment is to reduce clutter in raw data, emphasize mine-like characteristics, and make segmentation of the probable mine-containing zone easier during the post-processing stage. The results of full image data preparation suggested that full image pre-processing may cause clutter in the image to be redistributed, making mining feature discrimination more difficult. In such instances, segmentation utilizing thresholding approaches is likely to produce inaccurate results.

Table 5.2: Outcomes of Local Window-based Data at the end of the Convolution Step

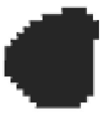
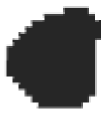
Data Processing Stages	**Dummy Anti-Tank Mine**
Raw data	 Figure 5.2 (a)
Convoluted data	 Figure 5.2 (b)

Local window-based data pre-processing, as described previously, was used to solve this challenge. With the exception of a narrow window, the rest of the image is repressed below the image's mean backscatter value. It creates a zooming effect for the window selected, resulting in a pre-processed image with easy-to-segment mine and non-mine characteristics. Table 5.2 demonstrate the outcomes of local window-based data preparation at the end of the convolution step. These results are then compared to those in Figures 5.2 (a) and 5.2 (b). It features a distinct dip in the middle, showing a change in backscatter in that area. As a result, it was discovered that local window processing produces substantially superior results and allows for accurate segmentation of the suspected minefield zone.

5.2 OTSU'S SEGMENTATION AND MAXIMUM ENTROPY BASED THRESHOLDING

Otsu's and maximum entropy-based thresholding approaches were used to segment the probable mine-containing zone. Table 5.3 show the results of the segmentation applying Otsu's thresholding for the antitank mines Figure 5.3 (a) illustrate the results of segmentation applying maximum entropy-based thresholding for the antitank mines Figure5.3 (b). However, because it is impossible to tell the difference between the two methods simply by looking at the segmentation results, the threshold values calculated by each of the two thresholding methods, the detection figures produced, and the number of pixels segmented were analysed. The threshold values for Otsu's thresholding approach range from 101 to 108.50, with the detection figure ranging from 51.46 to 61.33. Maximum entropy-based thresholding, on the other hand, yields threshold values of 98.60 to 106.79 and detection figures of 51.05 to 61.94. Except at a depth of 7 cm, the thresholding using the maximum entropy method provides lower threshold values than Otsu's threshold values. This is mirrored in the related detection figures, which are lower as well. It all adds up to better segmentation accuracy.

Table 5.3 Segmentation Results after Applying Otsu’s and Maximum Entropy-based Thresholding for the Anti-Tank Mines

Thresholding Method	**Otsu's Thresholding Method**	**Maximum Entropy-based Thresholding**
Dummy Anti-Tank Mine	 Figure 5.3 (a)	 Figure 5.3 (b)

The pixel count subdivided by each of the two thresholding approaches reinforces this even more. The image has a total of 24 × 24 pixels, which equals 576 pixels. The lowest number of pixels segmented at 1cm depth using Otsu's method is 362 (see Figure 5.3 (a) while it is 347 for the maximum entropy-based method (Figure 5.3

(b)). The discrepancy between these numbers is greater at all depths and for all other mines, but the maximum difference between the two is less than 5%.

5.3 POLARIZATION EFFECT ON SEGMENTATION

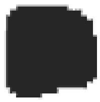
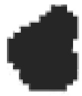
The corresponding lowest, maximum, and mean values of the data in HH and VV polarization for all mines demonstrated that the two data ranges are distinct. The VV polarization's backscatter was reported to be greater in each case. The standard deviation in the case of VV polarization was larger than in the case of HH polarization, indicating that it possessed more discriminating properties. The importance of data normalization during the pre-processing step was underlined by this. Table 5.4 shows the statistics calculation for dummy anti-tank mine. The third statistical moment, skewness, measures data asymmetry. A negative number implies asymmetry to the left of the mean, whereas a positive value suggests asymmetry to the right of the mean. The data was observed to be skewed to the left in both polarizations, although the data in VV polarization exhibited a larger skewness. Kurtosis is a fourth-order statistical moment that is also known to be outlier sensitive. A normal distribution's kurtosis is 3, with higher kurtosis values indicating more outlier prone distributions and lower kurtosis values indicating less outlier prone distributions. Each polarization's data had a Kurtosis value less than 3, but the VV polarization's data had a higher kurtosis value than the HH polarization's data. Further data preparation results in a small increase in these values, which aids discrimination even more.

Table 5.4: Statistics Calculation for Dummy Anti-Tank Mine

Mine	Pol	Data	Mean	Min	Max	Std Dev	Skewness	Kurtosis
Dummy Anti-Tank	HH	Raw	17.43	10.85	23.90	5.82	-0.21	1.07
		Cal.	8.72	0.40	20.65	5.34	0.19	1.53
		Con.	10.95	1.38	21.83	4.42	0.17	2.10
	VV	Raw	25.27	15.55	33.90	8.58	-0.24	1.06
		Cal.	7.62	1.10	15.95	2.64	0.07	2.69
		Con.	12.11	4.87	19.07	3.38	0.36	2.16

The study of these two statistical moments suggests that data in the HH and VV polarizations include distinct degrees of information, with skewness away from the mean indicating the presence of some object and low outlier sensitivity indicating little variation within the data distribution.

Table 5.5: Segmentation for HH and VV Polarisation

Operation	**Anti-Tank Mine at depth 1cm**	
Polarisation	HH	VV
Entropy Thresholding Detection		
Detection Figure	39.637	41.763

Figures 5.5 for antitank mine show the segmentation for each of the two polarizations. Although the thresholded readings may show where the mine is most likely to be found, there is considerable backscatter in the same thresholded range owing to noise. In addition, because of the residual antenna overlap or interference, the number of pixels segmented may not accurately represent the true mine pixels. It's possible that the majority of the debris would be in the same range as the mine features, causing any of the thresholding methods to fail. Though entropy-based approaches that include uniformity, shape, and other limitations are expected to perform well in such instances, there is still a need to improve data pre-treatment for accurate segmentation at the post-processing stage.

5.4 LOCAL WINDOW BASED PRE-PROCESSING EFFECT ON SEGMENTATION

The impact of data preparation using local windows was described in the preceding subsection. The approach is expanded in this part to include segmentation performed by local window-based data pre-processing. When full image data pre-processing is performed, Figures 5.6 (a) and (b) show the segmentation for a dummy antitank mine in both polarizations. When local window-based data pre-processing is used, the results are considerably better, as demonstrated in Figure 5.6 (c) and (d). One set of experiments was undertaken with all antitank dummy mine buried concurrently at a depth of 1.0 cm in a square pattern in order to validate the utility of local window-based data pre-processing.

Table 5.6 show the surface plots for mine at a depth of 1 cm following local window-based processing and entropy thresholding-based detection. The segmentation that was produced clearly outperforms any of the past results. In both polarizations, similar findings were found at all depths.

Table 5.6: Effect of Data Processing on Segmentation

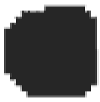
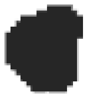
Operation	**Anti-Tank Mine at depth 1cm**	
Polarisation	HH	VV
Full Image processing	 Figure 5.6 (a)	 Figure 5.6 (b)
Local Window Processing	 Figure 5.6 (c)	 Figure 5.6 (d)

Table 5.7: Dummy Anti-Tank Mine in Smooth Sand

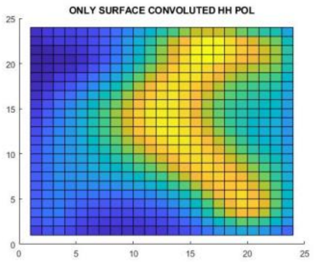
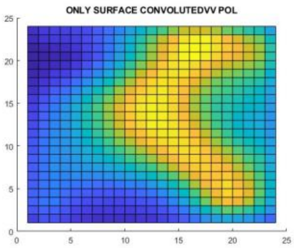
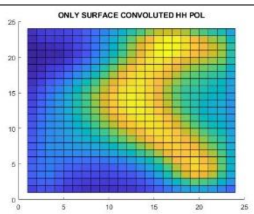
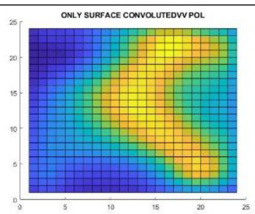
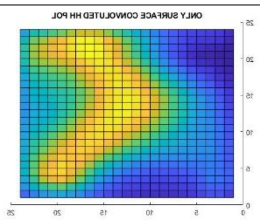
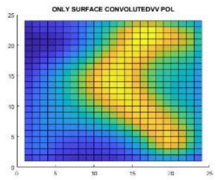
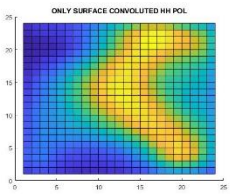
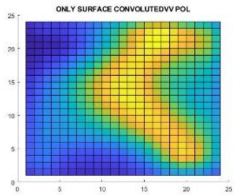
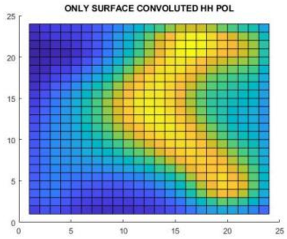
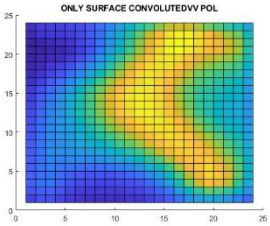
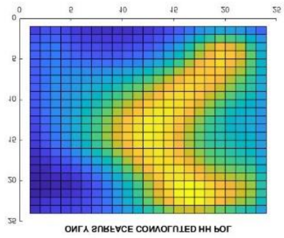
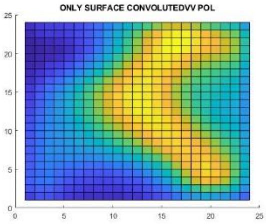
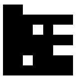
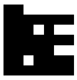
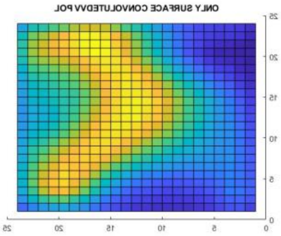
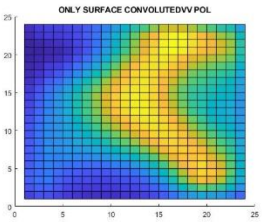
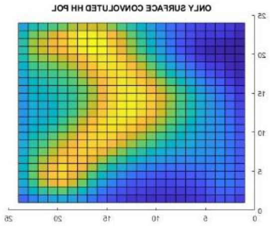
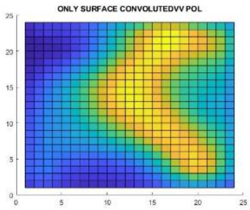
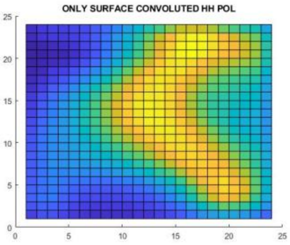
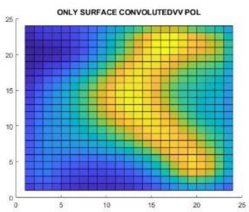
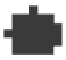
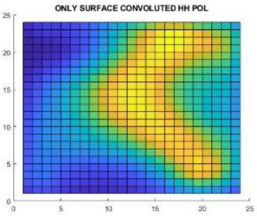
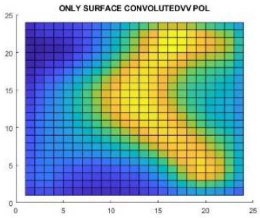
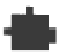
Dummy Anti-Tank Mine in smooth sand				
Surface Plot – Convoluted Data			**Entropy Thresholding**	
Depth	Polarization			
	HH	VV	HH	VV
0.5 cm				
1 cm				
1.5 cm				
2.0 cm				

Table 5.7 (Continued)

Dummy Anti-Tank Mine in smooth sand				
Surface Plot – Convoluted Data			**Entropy Thresholding**	
Depth	Polarization			
	HH	VV	HH	VV
2.5 cm				
3 cm				
4 cm				
5 cm				
7 cm				
10 cm				

5.5 DETECTION FIGURE TEST

Detection figures for dummy antitank mine were plotted versus depth. The outcomes were mostly the same in most of the cases. Figure 5.7 shows the detection figure plot for a dummy antitank mine.

The detection figures that provided correct results ranged from 45 to 75, according to the analysis. As a result, it was determined that if the detection figures were less than 40–80, there was no background landmine or any sub-surface object.

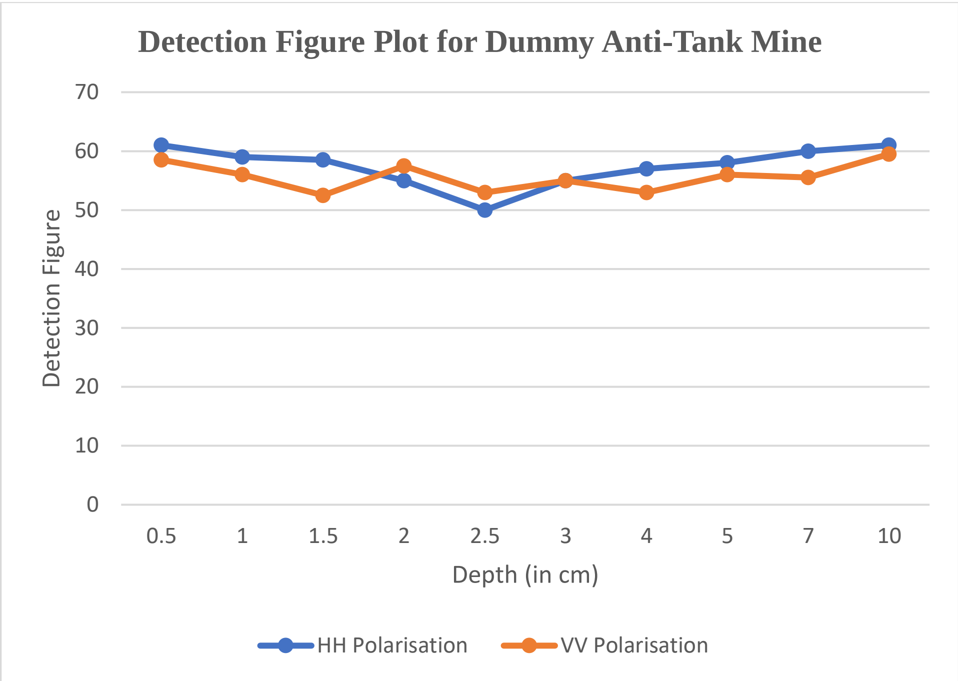


Figure 5.7 Detection Figure Plot for Dummy Anti-Tank Mine in Dry Smooth Sand in HH and VV Polarisation

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

The outward casing of a dummy landmine is identical to that of a live landmine, but it is devoid of explosives. On the other hand, the number of explosives in a live landmine varies depending on its type and intended use. The live landmine's dielectic behaviour is thus expected to be similar to that of the dummy landmine. As a result, a live antitank mine has been explored for testing under various lighting situations. The results show that, while the statistics computed for the live antitank mine differ from those derived for the dummy antitank mine, all of the patterns displayed by the live antitank mine in both polarizations are identical. The explanation for the disparity in statistics appears to be attributable more to differences in lighting circumstances than to the existence of explosive ingredients. Because the overall explosive content of the mine is around $1/7th$ to $1/10th$ of the total weight of the mine, dielectric fluctuations are unlikely to be substantial.

Landmine detection up to a depth of 10cm has been tested in the lab and in the field using microwave X-band frequency (10Ghz, 3cm). In the laboratory, data was collected using a dummy antitank landmine (without explosives) buried in dry smooth sand at various depths, as well as a live antitank mine (in the field). Raw data is processed using two separate methods: full image processing and local window processing. Data pre-treatment entails a series of image processing processes prior to segmentation utilising Otsu's and maximum entropy-based thresholding. Local window-based processing is found to highlight mine-like and non-mine-like characteristics more precisely than whole image processing, allowing for straightforward segmentation utilising two thresholding methods.

The usage of local window processing, on the other hand, may result in a longer processing time. The two thresholding methods have a minor difference in performance, with the maximum entropy-based method performing somewhat better in segmenting mine-like features with low variance from surrounding clutter. The findings were confirmed using the known location of the mine that was used in the trials. The presence of a landmine is indicated by a detection figure in the range of 30-80. The backscattered electric field was theoretically calculated using Daniels' suggested electromagnetic model. The backscattered electrical field detected was acquired from a segmented suspected landmine-containing zone.

6.2 FUTURE SCOPE

There is a great need for better performing target detection algorithms in real time data processing. Hence the development of better performing algorithms can revolutionize the remote sensing target detection application more importantly for defence and strategic interest targets. Moreover, the experiments have been restricted to dry sand only, which may be extended to soil with varying moisture conditions as well. Besides, research may be targeted to detect landmines located at higher depths as this research was only restricted to 10cm of depth. Also, depth and shape of the landmine may be estimated by using the target detection algorithm.

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MICROWAVE INSTRUMENT AND EXPERIMENTAL SETUP

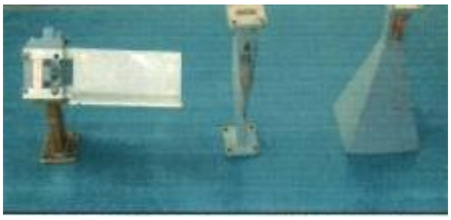
Components	Description
	Microwave signal generator source (Rohde & Schwarz SMR-27)
	Power meter (Rohde & Schwarz)
	(Left to Right) Circulator with an Isolator giving isolation of 35dB, Twister for changing E-plane and X-band antenna
	(Left to Right) Transmission/Reception cable with connectors and power meter sensor connecting antenna with the power meter

Figure A: Equipments and components used in the scatterometer system