TIME-FREQUENCY ANALYSIS FOR LANDMINE DETECTION USING
IMPULSE GROUND PENETRATION RADAR

BY
BIRHANEYESUS G/TSADIK

THESIS SUBMITTED TO ADDIS ABABA INSTITUTE OF
TECHNOLOGY IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
ELECTRICAL ENGINEERING

ADVISOR:
Dr.YALEMZEWD NEGASH

JANUARY, 2017
ADDIS ABABA, ETHIOPIA
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

TIME-FREQUENCY ANALYSIS FOR LANDMINE DETECTION USING IMPULSE GROUND PENETRATION RADAR

BY

Birhaneyesus G/tdak

Approved by Board of Examiners

Dr. Yalemzewd Negash
Chairman, Dept. Graduate Committee

Signature
Date

Dr. Yalemzewd Negash
Advisor

Signature
Date

Internal Examiner
Signature
Date

External Examiner
Signature
Date
Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

Name: Birhaneyesus G/tsadik
Signature: _________________________
Place: Addis Ababa
Date of submission: _________________

This thesis work has been submitted for examination with my approval as a university advisor.

Dr.Yalemzewd Negash
Advisor’s Name

______________________________
Signature
Acknowledgment

I really appreciate to my Advisor Dr. Yalemzewd Negash for his unreserved guidance, emails to get a real data, suggestions and advices during the total work of this thesis.

Next prof. Abdulhak M. Zoubir from Darmstadt university in Germany for accepting my question to get a real data of GPR through my advisor Dr. Yalemzewd Negash and allowed me to get that real data from Assistant Prof. G/Michael Teame in Mekelle university.

My heartfelt gratitude also goes to Assistant Prof. G/Michael Teame from Mekelle University for his invaluable assistance in giving a real data of GPR system that he has collected in Germany while doing his PhD thesis under his advisor prof. Abdulhak Zoubir.

Lastly, Addis Ababa institute of Technology (AAiT) also deserves acknowledgement for funding this thesis work. I also thank instructors of communication engineering for their constructive suggestions on this work.
Abstract

Land mine detection is an important and yet challenging problem and one that remains to be solved. Ground Penetrating Radar (GPR) is an effective sensor to detect land mines that are made of plastic or have low metal content.

GPR operates by first transmitting an impulse signal down to the mine field, second receives the signals reflected from the different layers of the ground and processes the received image to give a revealing picture of the size and shape of a landmine (metal or plastic) and where exactly it is located.

In electromagnetic wave propagation modeling, a multilayer transmission line technique is applied. It considers different soil types and targets of different diameters which are buried at different depths. Signal processing algorithms are implemented for clutter reduction. Preprocessing techniques such as DC Offset removal, Antenna cross talk, Noise Reduction (using weighted moving average and exponential moving average) and Background clutter reduction. GPR signal processing algorithms apply processing in time domain; therefore an advanced signal processing technique which is a 2D (time and frequency) view of a signal is required to see a more revealing picture.

After preprocessing steps have been accomplished then further process with advanced signal processing techniques to get a more revealing picture of the energy concentration of the buried target at different time instants. Joint time-frequency transforms were developed for the purpose of characterizing the time-varying frequency content of a signal. The best-known time-frequency representation of a time signal dates back to Gabor and is known as the short-time Fourier transforms (STFT). It is basically a moving window Fourier transforms. By examining the frequency content of the signal as the time window is moved, a 2D time-frequency distribution called the spectrogram is generated. The spectrogram contains information on the frequency content of the signal at different time instances.

Considering a real GPR data [1] where target objects and non target objects or clutters which are buried at different positions and after passing through Matlab algorithms, a more revealing picture is created.

Keywords; land mine detection, GPR system, demining.
Table of Contents

<table>
<thead>
<tr>
<th>Content</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Declaration</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgment</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vii</td>
</tr>
<tr>
<td>List of Abbreviations and Symbols</td>
<td>viii</td>
</tr>
<tr>
<td>CHAPTER ONE</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Statement of Problem</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Objectives</td>
<td>3</td>
</tr>
<tr>
<td>1.4 Merits of the Thesis</td>
<td>4</td>
</tr>
<tr>
<td>1.5 Scope of the Thesis</td>
<td>5</td>
</tr>
<tr>
<td>1.6 Limitations</td>
<td>6</td>
</tr>
<tr>
<td>CHAPTER TWO</td>
<td>7</td>
</tr>
<tr>
<td>Literature Review</td>
<td>7</td>
</tr>
<tr>
<td>2.1 Metal Detectors</td>
<td>7</td>
</tr>
<tr>
<td>2.2 Biological Detection</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Thermal Imaging</td>
<td>7</td>
</tr>
<tr>
<td>2.4 Nuclear Quadrupole Resonance</td>
<td>8</td>
</tr>
<tr>
<td>2.5 Ground Penetrating Radar</td>
<td>8</td>
</tr>
<tr>
<td>CHAPTER THREE</td>
<td>10</td>
</tr>
<tr>
<td>GPR System Overview</td>
<td>10</td>
</tr>
<tr>
<td>3.1 Ground Penetration Radar (GPR)</td>
<td>10</td>
</tr>
<tr>
<td>3.2 GPR data presentation types</td>
<td>12</td>
</tr>
<tr>
<td>3.3 GPR surveying methods</td>
<td>13</td>
</tr>
<tr>
<td>3.4 Electromagnetic wave propagation modeling</td>
<td>14</td>
</tr>
<tr>
<td>3.5 Electromagnetic Properties of Materials</td>
<td>16</td>
</tr>
<tr>
<td>3.5.1 Dielectric permittivity (ε)</td>
<td>16</td>
</tr>
<tr>
<td>3.5.2 Magnetic Permeability (μ)</td>
<td>16</td>
</tr>
</tbody>
</table>
3.5.3 Conductivity ($\sigma$) ......................................................................................................................... 17
3.5.4 Wave velocity ($v$) ............................................................................................................................ 17
3.6 Mathematical modeling ......................................................................................................................... 18
3.7 Signal Pre-processing Techniques ........................................................................................................ 22
3.7.1 DC Offset removal (Dewow filtering) ............................................................................................... 22
3.7.2 Clutter Reduction Techniques ......................................................................................................... 22
3.7.3 Antenna cross talk ............................................................................................................................. 22
3.7.4 Noise Reduction ................................................................................................................................. 23
3.7.5. Background clutter reduction ......................................................................................................... 24
3.8 Advanced Signal Processing Techniques ............................................................................................ 27
3.8.1 Time frequency analysis .................................................................................................................. 27
3.8.2. The short time Fourier transform (STFT) ...................................................................................... 28
CHAPTER FOUR ....................................................................................................................................... 30
Methodology ............................................................................................................................................... 30
CHAPTER FIVE ........................................................................................................................................ 32
Results and Discussion ............................................................................................................................... 32
  5.1. Collected data ................................................................................................................................... 32
  5.2. Processing of the collected data ....................................................................................................... 33
  5.4. The time frequency analysis ............................................................................................................... 36
CHAPTER SIX ........................................................................................................................................... 38
Conclusion and Recommendation .............................................................................................................. 38
List of Figures

Figure 3.1 Typical GPR system block diagram [1, 3].................................................................11
Figure 3.2 Co-ordinate system for scan description....................................................................12
Figure 3.3. GPR geophysical surveying modes.........................................................................14
Figure 3.4. Layout of transmission line modeling [3].................................................................15
Figure 3.5. Imaging process of GPR data [30]............................................................................15
Figure 3.6. Equivalent circuit for transmission line.................................................................19
Figure 3.7. Typical GPR transmitter/receiver configuration......................................................21
Figure 3.8: Model for background subtraction..........................................................................24
Figure 5.1. Unprocessed Bscan.................................................................................................32
Figure 5.2. Offset removed Bscan.............................................................................................33
Figure 5.3. Noise removed Bscan using exponential Moving Average techniques.....................34
Figure 5.4 background removed Bscan using Running Mean technique..................................35
Figure 5.5. Image of Running Mean data using STFT of Hann window size 49.....................36
Figure 5.6 Image of Running Mean data using STFT of Hann window size 100....................37
**List of Abbreviations and Symbols**

**A/D:** Analog to Digital

**β:** phase constant

**C:** capacitance

**c:** speed of light

**d:** depth

**DC:** Direct Current

**2D:** Two Dimensional

**E:** Electromagnetic field

**EM:** Electromagnetic Wave

**GPR:** Ground Penetrating Radar

**G:** Conductance

**ha:** Antenna height

**IEEE:** Institute of Electrical and Electronics Engineers

**η:** Intrinsic impedance

**R:** Resistance

**L:** Inductance

**σ:** Conductivity

**α:** Attenuation constant

**μ:** Magnetic permeability

**γ:** Propagation constant
T: Transmission coefficient

Γ: Reflection coefficient

ω: Angular velocity

t: time

Tx: Transmitter

Rx: Receiver

STFT: Short Time Fourier Transform

V: voltage

ν: wave velocity

ARMA: Autoregressive Moving Average

PMN1: PolyMorphonuclear Neutrophil

PVC: polyvinyl chloride
CHAPTER ONE

Introduction

1.1 Background

Landmines are explosive mines laid on or just under the surface of the ground during a conflict against enemy forces that can still kill or injure civilians decades after the war has ended [1–2]. Landmines indiscriminately kill or maim whoever triggers them, whether a child, a woman or a soldier. Mines can be found anywhere: in fields, along rivers, in urban areas, on transport routes and in surrounding villages [2-4].

Ground penetrating radar (GPR) is an emerging technology that provides centimeter resolution to locate even targets that are too small. It is an electromagnetic technique that is designed primarily to investigate roads, bridges and subsurface objects. Impulse GPR has been considered as a viable technology for the detection of buried landmines without affecting the environment where the targets are [1, 3].

The existence of large contrast between the air and the soil medium causes a strong bounce that returns from the interface which usually obscures the weak signature caused by the buried plastic landmine [5, 6, 7].

The signal reflected from buried plastic landmines is subjected to strong background clutter, noise and distortions. Hence, one of the main challenges of using GPR for landmine detection is to remove the ground bounce as completely as possible without altering the landmine return[2, 8].

The aim of this thesis work is to develop a matlab code for all the preprocessing techniques and advanced signal processing techniques to create more revealing picture of the landmine.
1.2 Statement of Problem
GPR is a sensor with sophisticated sensors and signal processing that assist deminers to achieve faster and reliable demining.

Limited performance of signal processing techniques for deminers matters a lot on the shape and size information of the mine that can be drawn from the data.
1.3 Objectives

General Objective:

This thesis work is aimed at signal processing of buried land mine’s using impulse GPR by taking a real impulse GPR system data.

Specific Objectives:

The specific objectives of this thesis work are:

- To make GPR system simple to operate, reliable and to use at different types of soils and topologies.
- To detect metallic and non metallic or those having small metal contents which are buried deep the ground.
- To employ Sequences of preprocessing and advanced signal processing techniques for a real GPR data to give a clear display of the mine.
1.4 Merits of the Thesis

The application of ground probing radar for landmine detection is only a recent development (about 15 years [2]) that needs to be researched even more. Once a researcher in the field of landmine detection using ground probing radar knows how the pre-processing of actual GPR data, and in addition one among the advanced signal processing techniques i.e. time-frequency analysis, could be done using matlab, it would be easy and inviting for him/her to employ GPR for landmine detection. This thesis shows how some of the preprocessing techniques and the time-frequency analysis techniques can be realized using matlab so that researchers in the field develop matlab codes to realize the other techniques also.
1.5 Scope of the Thesis
The scope of this thesis work is starting from modeling of a GPR system based on the theoretical mathematical model of the system and an actual measured data that has been collected by [1] has been considered. The modeling began with the signal transmitted from the GPR transmitter antenna i.e. an impulse signal; and this impulse signal was sent through noisy channel down to the ground to reach the target mine. Reflections from each sub surface of the ground as the signal passes down to the target will be collected by the receiver antenna (represented as the sum of the time delayed versions of the noised impulse signal). Then an image of the received data created. Then this image passed through a sequence of pre-processing steps like offset removal, noise removal, background, clutter removal and time-frequency analysis.

A matlab code has been developed to realize them and finally a conclusion has been drawn from these results.
1.6 Limitations
Since GPR system is not easily available, considering in case of Ethiopia for different land mines which are buried at different soil types and topologies was not tasted.
CHAPTER TWO

Literature Review

Finding buried landmines is a difficult task, because landmines have variations in size, shape, composition and depth.

2.1 Metal Detectors

Metal Detectors measure the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in the soil. Metal Detector is capable of detecting even low-metal content mines in mineralized soils [18, 19, 20]. Metal Detector is a matured technology, but cannot detect plastic or nonmetallic landmines, although most modern landmines have no metallic content except the striker pin. Increasing the sensitivity of detecting small metallic objects makes it susceptible to high false alarm rates [7, 20].

2.2 Biological Detection

Trained dogs, rats, pigs, bees and birds can smell the explosive within the mines. Dogs can reliably detect $10^{-12}$ to $10^{-13}$ g of explosives [18]. Even though they detect small explosives, they are hindered by inclement weather, terrain, tiredness and health issues. Moreover, they do not detect the actual location of the mine [1, 2, 15, 20].

2.3 Thermal Imaging

Mines retain or release heat at a rate different from their surroundings. Infrared (IR) cameras create images that reveal the thermal contrast between the soil immediately surrounding a buried mine and the top layer of the soil [1]. If the contrast is from a mine, it shows a volume effect; however, if the contrast is due to disturbed soil, it shows a surface effect [18]. Thermal Imaging requires highly sensitive IR cameras and the detection depends on the environmental conditions [1, 20].
2.4 Nuclear Quadrupole Resonance

Induces radio frequency pulses that cause the chemical bonds in explosives to resonate [21]. The detection is limited to liquid explosives, radio frequency interference, quartz-bearing and magnetic soils.

2.5 Ground Penetrating Radar

GPR technology, which has been used in civil engineering, geology and archeology since 1970s. GPR detects the dielectric contrasts in the soil that allows to locate even nonmetallic mines. This ultra-wide band radar provides centimeter resolution to locate even a small target [1, 2]. GPR has rapid survey capability and near-real time data interpretation in many cases. Unfortunately, this technology can suffer from false alarms as high as that of metal detectors [1,2,3,7].

Although this technology has limitations, in particular, the resolution needed to detect small objects involves GHz frequencies, which decreases soil penetration and increases image clutter. Ground Penetrating Radar is an emerging technique for landmine detection that can detect plastic and low metal content landmines [1,2,19].

Ground Penetrating Radar (GPR) is an effective sensor to detect land mines that are made of plastic or have low metal contents to get a clear display of the image using different types of processing techniques [4].

GPR provides centimeter resolution to locate even small targets. GPR has rapid survey capability and near-real time data interpretation in many cases. Unfortunately, this technology can suffer from false alarms as high as that of metal detectors [3, 7]

A lot of works have been done on land mine detection using impulse GPR in different parts of the world [2]. In the area of academics, the following are some of the works done on the issue of land mine detection using impulse GPR.

Zoubir et al. in [1, 3] investigated the detection performances of various signal processing techniques with emphasis on a Kalman filter based approach. Compared to others, this technique showed the best overall performance. However, the cost of the Kalman filter approach shows substantial increase in the computational load.
Alvaro et al. in [23] applied many background subtraction techniques for their optimality. They compared the techniques based on their energy to clutter ratio. Frequency domain scaled and shifted background subtraction was found to be optimal for rough and smooth ground surfaces.

Dragana C. in [24] and [26] considered a Kalman filtering approach and wavelet packet decomposition for clutter reduction applications. Yuan and Guang in [25] also considered a Kalman filtering approach to reduce the ground clutter.

Van Kempen in [27] and Brooks in [29] proposed an autoregressive moving average (ARMA) model for the contained clutter. In practice, the ARMA parameters of the clutter and the clutter-plus-target were so close that a meaningful target separation was not possible [28].
CHAPTER THREE

GPR System Overview

3.1 Ground Penetration Radar (GPR)

GPR is widely used in detecting subsurface objects such as buried landmines, unexploded ordnance, and utility lines. Compared with other subsurface sensing technologies, GPR is non destructive testing equipment. GPR geophysical method is a rapid, high-resolution tool for non-invasive investigation.

GPR operates by transmitting an electromagnetic signal into the sub-surface and detecting a target reflected signal at a receiver. The target reflection is due to the dielectric discontinuity between the target and the medium [6]. This technique is able to detect buried non-metallic mines, can be used to detect both small and large diameter mines based on the frequency of operation. False alarm rate of this technique is high; but there are methods to reduce the false alarm rate to a tolerable extent.

GPR records microwave radiation that passes through the ground and is returned to the surface. The radar waves propagate at velocities that are dependent upon the dielectric constant of the subsurface, and reflections are caused by changes in the dielectric contrast that are due to changes in the subsurface medium. A transmitter sends a microwave signal into the subsurface and the time it takes energy to return to the surface relates to the depth at which the energy was reflected [9]. Thus, interpretation of this reflected energy yields information on structural variation of the near subsurface. Ground Penetrating radar transmitters operate in the megahertz range and the choice of source signal peak frequency correlates to expected depth of penetration and resolution. Higher frequency sources will offer greater vertical resolution of structure but will not penetrate as deep as lower frequency sources. The choice of appropriate source will be target and project-goal dependent.
GPR data are most often collected along a survey profile, so that plots of the recorded signals with respect to survey position and travel-time can be associated with images of geologic structure as a function of horizontal position and depth. Ground penetrating radar can be collected fairly rapidly, and initial interpretations can be made with minimal data processing.
3.2 GPR data presentation types

GPR data can be represented in three different forms: A-scan, B-scan and C-scan.

**A-scan** is a one-dimensional plot and also called a trace. It is a sequence of sample points collected by the GPR at a fixed antenna position that indicates a time variation of the recorded signal amplitude [9, 22]

**B-scan** is a two-dimensional plot representing an ensemble of A-scans as GPR moves in a straight line above the ground surface. The horizontal axis represents the scan length or number of traces, whereas the vertical axis represents the range or the time elapsed for the pulse to return.

**C-scan** is a three-dimensional display of GPR data resulting from the side-by-side arrangement of stacked B-scans. It is also represented by a collection of horizontal slices where each slice corresponds to a particular depth or a certain sample point.

Figure 3.2 Co-ordinate systems for scan description [3]
3.3 GPR surveying methods

GPR has four surveying modes depending on how the transmitter and receiver antenna moves and the spacing between the antenna set during the survey. These are common source, common offset, common depth and common receiver.

1. Common source: the transmitter is fixed, however, the receiver moves along the survey direction.
2. Common offset: both antennas move together in the direction of survey with a fixed offset or spacing between the units.
3. Common depth or common point: the transmitter and receiver antenna, move away from a common point in opposite direction.
4. Common receiver: the receiver is fixed, while the transmitter moves along the survey direction.

The most common and widely used form of GPR surveying mode deploys a transmitter and a receiver in a fixed geometry (common offset), where the antenna set moves over the surface [6,9]. With this measurement mode, one can efficiently and quickly obtain information about the near-surface underground structure. The common depth, common source and common receiver survey modes require different signal processing techniques to interpret the data.
3.4 Electromagnetic wave propagation modeling

The transmission line models are identical to Maxwell’s equations in one dimension for Ground Penetrating Radars.

The most basic model is that of the transmission line equivalent and is useful for assessing the time domain signature of a physical situation. An Electromagnetic wave propagated from a GPR sees different media of different electrical properties, such as air, soil, air-gap, some targets and then different soil layers. Assuming that transmitted wave looks directly into different layers and based on the analogy between uniform plane wave and transmission line models, a transmission line model can be described that matches the same scenario as seen by the transmitted EM wave \[1,3,13\].
GPR transmits short pulses of high frequency electromagnetic into the ground. These waves propagate with a velocity that depends on the dielectric property of medium. If the waves encounter a buried object with different reactive indices, some of the waves are reflected back and the receiver processes them to create a hyperbolic image as the object representation. In order to create an image, the GPR transmits electromagnetic pulses at a certain frequency for a certain time slot and samples the response as an A-scan corresponding to a single position of the GPR. By moving the GPR in the x-direction, a collection of these A-scans called a B-scan which representing different GPR positions are constructed. Then it is processed become a hyperbolic image. Ideally, the imaging process of GPR data is described in figure 3.5.
3.5 Electromagnetic Properties of Materials

The behavior of a propagating EM wave depends on the properties of the medium through which it propagates. The velocity of the propagation, the fraction which is bounced back or transmitted, the amount of attenuation and loss are dependent on the electromagnetic properties of the media and frequency of propagation. The most important electromagnetic properties of these materials are: dielectric permittivity, magnetic permeability and electric conductivity. Different dielectric materials have different electromagnetic properties. The nature of dielectric materials affects the propagation behavior of the electromagnetic wave. The significance of the electromagnetic properties of the media is described in the following subsections.

3.5.1 Dielectric permittivity (\(\varepsilon\))

The dielectric permittivity or simply permittivity of a medium is a measure of the material’s ability to allow the formation of an electric field within it \([6,9]\). In other words, it is a measure of how an electric field affects and is affected by a dielectric medium. Absolute permittivity is expressed relative to free space permittivity, which is assumed to be the same as the permittivity of vacuum. The relative permittivity also called the dielectric constant, \(\varepsilon_r\), of a material is the ratio of its permittivity to that of free space.

3.5.2 Magnetic Permeability (\(\mu\))

Magnetic permeability (\(\mu\)) is the ability of a material to support the formation of a magnetic field within it. The relative permeability of a material is the ratio of its permeability to that of free space, i.e, \(\mu_r = \mu/\mu_0\), and is a unitless quantity. Magnetic permeability has little effect on the propagation of a GPR wave and therefore, the magnetic permeability of subsurface materials is often assumed to be equal to the free space value, \(\mu_0\). Ferromagnetic materials with a relative permeability, \(\mu_r \gg 1\), have considerable effect on the EM wave propagation velocity and attenuation. They are also considered to be magnetically lossy and may have a frequency dependent permeability. For ferromagnetic materials, the permeability can have an imaginary component. Soil and subsurface materials are mainly non-ferromagnetic (\(\mu_r \approx 1\)), therefore, they are assumed to be the same as free space (\(\mu_r = 1\)) \([13]\).
3.5.3 Conductivity ($\sigma$)

In simple terms, conductivity describes the ability of a material to pass free electric charges under the influence of an applied EM field. Electrical conductivity is a measure of the material’s ability to conduct an electric current and is measured in S/m. Conductivity has a significant effect on the attenuation of a radar signal. For soils and ground materials, conductivity is assumed to be isotropic, having the same value in each direction. Metallic landmines have higher conductivity, whereas plastic landmines have low conductivity. Soils have conductivity in the range of 0.0001 to 0.1 (S/m) and free space has zero conductivity [3,13].

3.5.4 Wave velocity ($v$)

The propagation velocity of an EM wave in free space is assumed to be the same as in vacuum, $c$, but depending on the relative permittivity and relative permeability of a medium reduces to $\frac{c}{\sqrt{\mu_r \varepsilon_r}}$. The velocity at which the wave travels through medium is proportional to the angular velocity of the wave [3,13].
3.6 Mathematical modeling
When an EM wave propagates through one medium and enters another medium with different electrical parameters (relative permittivity, conductivity and magnetic permeability), then it experiences reflection and transmission based on the relative difference in those properties [13]. Each reflected pulse will be subjected to inter-medium sub-reflections as it travels back to Radar. The pulse of interest is the one that reflects back from the target. The received signal is the superposition of all the reflected pulses. The magnitude of the reflected signal is the product of initial pulse magnitude and transmission & reflection coefficient of each intervening material. The pulse also gets attenuated depending on the attenuation constant and length of each material. Each layer is modeled as an equivalent impedance $\eta_n$, based on the electrical characteristics. Using the impedance values the transmission $T_{ij}$ and reflection coefficient $\Gamma_{ij}$ are also calculated for each interface. The model also calculates the propagation constants $\alpha_n$ and $\beta_n$, percentage of attenuation and equivalent time for each layer [3, 6, 13].

Propagation of an electromagnetic field $E_0$ originating at $z = 0$, $t = 0$ in a conducting dielectric can be described by $E(z, t)$ at a distance, $z$, and time, $t$.

$$E(z, t) = E_0 e^{j\omega t} e^{-(\alpha + j\beta)z} \quad (3.1)$$

Where $\alpha, \beta$ are attenuation and phase constant respectively

$\gamma = \alpha + j\beta$ is propagation constant

In a lossy dielectric having permittivity $\varepsilon$, conductivity $\sigma$ and permeability $\mu$, propagation constant is given by

$$\gamma = \alpha + j\beta = \pm \sqrt{j\omega \mu (\sigma + j\omega \varepsilon)} \quad (3.2)$$

Where

$$\alpha = \omega \sqrt{\frac{\mu \varepsilon}{2}} \sqrt{1 + \left(\frac{\sigma}{\omega \varepsilon}\right)^2 - 1} \quad \text{and} \quad \beta = \omega \sqrt{\frac{\mu \varepsilon}{2}} \sqrt{1 + \left(\frac{\sigma}{\omega \varepsilon}\right)^2 + 1}$$

$\mu$ is magnetic permeability in Henry/meter

$\sigma$ is conductivity of the material in Siemens/meter
ω is frequency in rad/sec

ε is farad/meter

The complex intrinsic impedance η of the medium (lossy dielectric) is given by

\[
\eta = \frac{E_x}{E_y} = \frac{j\omega \mu}{\sigma + j\omega \epsilon}
\]  (3.3)

For a dielectric material loss phasor termed as Loss Tangent δ is defined as

\[
\tan(\delta) = \frac{\sigma}{\eta \epsilon}
\]  (3.4)

Figure 3.6. equivalent circuit for transmission line

For a transmission line model given in Figure 3.6 above, voltage wave equations are given by

\[
V_x = V_0 e^{-\gamma z}
\]

\[
\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}
\]

Where, \(\gamma\) is the propagation constant, 'R' is resistance in Ohm/m, 'L' is inductance Henry/m, 'G' is conductance in Siemens/m and 'C' is capacitance in Farad/m.

The Intrinsic impedance is given by

\[
Z_0 = \frac{V_x}{I_x} = \frac{R + j\omega L}{G + j\omega C}
\]  (3.5)
By comparing the EM propagation voltage equations with the transmission line voltage equations above we let $V = E$, $I = H$, $R = 0$, $L = \mu$, $G = \sigma$ and $C = \epsilon$, and $\eta = Z_0$, then a transmission line model is identical to the uniform plane wave propagation model.

At the boundary between two media, some energy will be reflected and the remainder transmitted. The reflected field strength is described by the reflection coefficient is given by:

$$\Gamma_{ij} = \frac{\eta_j - \eta_i}{\eta_j + \eta_i}$$

(3.6)

And the transmission coefficient is calculated as

$$T_{ij} = \frac{2\eta_i}{\eta_j + \eta_i}$$

(3.7)

It can easily be recognized that if the propagation velocity can be measured, or derived, an absolute measurement of depth or thickness can be made. For homogeneous and isotropic materials, the velocity of propagation of an EM wave in a medium is

$$V = \frac{1}{\sqrt{\mu \epsilon}} = \frac{c}{\sqrt{\mu_r \epsilon_r}}$$

and $C = \frac{1}{\sqrt{\mu_r \epsilon_r}}$

And the depth is then calculated as

$$d = V \frac{t}{2}$$

(3.8)

A pulse signal sent by the transmitter antenna of the GPR gets mixed with surrounding noise or can directly communicate with the receiver antenna, called cross-talking of the antennas. Some of the signal may be reflected from the air-ground interface and some part of the incident signal will be refracted and then reflected when it encounters a target (landmine or landmine objects). Figur.3.7.below shows how the transmitted signal behaves in its way from transmitter to the receiver antenna.
The general signal model is given by

\[ u(t) = S_c(t) + S_b(t) + S_t(t) + n(t) \]  \hspace{1cm} (3.9)

Where, \( u(t) \) is total received signal

\( S_c(t) \) is signal due to antenna crosstalk

\( S_t(t) \) is signal reflected from the target

\( S_b(t) \) is signal bounced from the air-ground interface

\( n(t) \) is added noise

Figure 3.7. Typical GPR transmitter/receiver configuration [3]
3.7 Signal Pre-processing Techniques

3.7.1 DC Offset removal (Dewow filtering)
Dewow is the removal of the initial DC signal component, or DC bias or low frequency signal present in the data. This is sometimes called a 'Zero offset'. Wow is caused by the saturation of the recorded signal by early arrivals and/or inductive coupling effects and requires the subtraction of the DC bias from the signal. The process of removing the wow is called dewow or zero offset removal. Dewowing is a vital step as it reduces the data to a mean zero level. This assumes that the amplitude probability distribution of the A-scan is symmetric about the mean value and not skewed and that the short time mean value is constant over the time duration of the A-scan. Zero offset can be removed using the following algorithm [3,6]

\[ A'_n(t) = A_n(t) - \frac{1}{N} \sum_{n=1}^{N} A_n(t) \]  

(3.10)

Where

\( A'_n(t) \rightarrow \) is processed data sample

\( A_n(t) \rightarrow \) is unprocessed data sample

3.7.2 Clutter Reduction Techniques
The received data consists of four signal components, namely, the antenna cross-talk, the air-ground interface reflection, the background resulting from scatterers within the soil and the target scattered signal. Two of them, noise and antenna cross talk, can be reduced by proper system design or by proper signal processing [3].

3.7.3 Antenna cross talk
The antenna crosstalk is a quasi stationary signal part, which can be eliminated by time window gating. By estimating the shortest time required the impulse to reach and return from the ground surface, we can ignore signals arriving before the shortest time [3,6].

The shortest time required for the EM wave to reach the ground surface is given by

\[ t_c = \frac{h_a}{c} \]  

(3.11)
Where,

\( c \rightarrow \) is the speed of light in free space = \( 3 \times 10^8 \) m/s

\( h_a \rightarrow \) is the height of the antenna from the ground

Then the received signal becomes

\[
 u(t) = \begin{cases} 
 S_b(t) + S_t(t) + n(t), & \text{if } t \geq 2t_c \\
 0, & \text{if } t < 2t_c 
\end{cases} 
\]  
(3.12)

This is sometimes called time-zero correction, i.e., correction of start time to match with surface position.

### 3.7.4 Noise Reduction

Noise reduction can be achieved by either exponential moving average or using weighted moving average. The general effect is to reduce the variance of the noise and gives an improvement in signal to noise ratio [3].

#### 3.7.4.1. Weighted moving average

\( S(t) \) is given by;

\[
 S(t) = \frac{nxt + (n-1)x(t-1) + \ldots + 2x(t-n) + x(t-n-1)}{n(n-1) + \ldots + 2 + 1} 
\]  
(3.13)

Where,

\( S \rightarrow \) is smoothed signal in the A scan

\( n \rightarrow \) is window width Note: that negative indices of \( x \) are assigned to be zero.
3.7.4.2. The exponential moving average

s(t) for signal x(t) is given by

\[ s_t = \frac{N-1}{N} s_{t-1} + \frac{1}{N} x_{t-1}, \quad \text{for } t \geq 2 \] (3.14)

Where;

N is any positive integer greater than 2, the greater the value of N the better will be the smoothing.

3.7.5. Background clutter reduction

The Signal model for background subtraction is [3]

![Model for background subtraction](image)

Figure 3.8: Model for background subtraction [3]

The above model is expressed analytically as

\[ x(t) = \eta \cdot s(t) + b(t), \quad -\infty < t < \infty \] (3.15)

Where

\( x(t) \) is measured signal

\( s(t) \) is target signal

\( b(t) \) is background signal

The received signal is assumed as a superposition of the background signal and scaled target signal. Most of the incident impulse signal is reflected from the air-ground interface. This is due to the difference in permittivity and conductivity of air (\( \sigma_a, \epsilon_{ra} \)) and ground (\( \sigma_g, \epsilon_{rg} \)) gives rise to high difference in impedance and higher reflection factor. Air-ground interface reflection can be removed by placing the GPR in direct contact with the soil so that no air ground reflection is allowed to form. However, this is not possible for the application of landmine detection. A simple
and widely used approach to reducing this type of clutter in GPR data is background subtraction. Assuming the ground surface is varying slowly, the background signal is estimated as the mean or median of the unprocessed ensemble of GPR signals received over the area of interest using either all signals in the ensemble or a spatial moving average filter to obtain a locally adaptive background estimate. This estimate is then subtracted from the unprocessed GPR signals in the ensemble.

The objective is to test the presence of a target

\[ H_0 : \eta = 0, \text{Target free} \]
\[ H_1 : \eta \neq 0, \text{Target present} \]

This suggests a test statistic

\[ T_{bs} = \text{Max}_t |x(t) - \hat{b}(t)| \]  \hspace{1cm} (3.16)

Where

- \( x(t) \rightarrow \) is unprocessed GPR signal
- \( \hat{b}(t) \rightarrow \) is background estimate

The null-hypothesis \( H_0 \) is rejected if the statistic \( T_{bs} \) is greater than the threshold \( T(\alpha) \), where the Threshold is obtained empirically.

**Simple mean** takes the mean of the data across a specified time window and smooth the data. This is good for removing excessive higher-frequency noise from the data such as radio frequency interference from communication devices.

**Simple median** takes the median of the data across a specified time window. This is good for power spike removal and are often referred to as despiking or clean-up filters.

### 3.6.5.1. Average of All Traces

In this case, the background is estimated only once as the average or median of all the traces. The Background is estimated as:

\[ b_{Mn}(t) = \frac{1}{N_a} \sum_{a=1}^{N_a} x_{n,a}(t) \]  \hspace{1cm} (3.17)
3.7.5.2. Running Mean/ Median Estimate

The background signal can be estimated using an appropriately wide moving window and taking the average or median of the surrounding traces. Wider window allows to estimate the background accurately with low variance and a narrow window helps to avoid introducing effects from changes in the background.

For 'M' wide window, the running mean estimate of the background is:

\[
b_{Mn}(k,j) = \frac{1}{2M} \sum_{r=j-M+1}^{j+M} x(k,r)
\]

And running median estimate of the background is:

\[
b_{Md}(k,j) = \text{median} \{x(k,j-M+1), \ldots, x(k,j+M)\}
\]

By using the running mean and running median, we can adaptively estimate the changes in background. The main problem associated with the running mean and running median is, in choosing appropriate window length.

Background subtraction techniques are very simple to calculate the background estimate. The main disadvantage of the background subtraction methods is that the target reflection will be affected by the subtraction process, so that specific target scattering information, which can be used for target classification, will be lost.
3.8 Advanced Signal Processing Techniques

Now that the necessary preprocessing steps have been accomplished but in need of further processing of the data with advanced signal processing techniques to get a more revealing picture of the energy concentration of the buried target.

There are two distinct types of GPR: time-domain and frequency-domain. Time domain or impulse GPR transmits discrete pulses of nanosecond duration and digitizes the returns at GHz sample rates. The time domain radars are relatively simple, cheap and robust. The weak points of the time-domain approach are a low signal-to-noise ratio (SNR) and typically low accuracy of the measured data. The frequency domain GPR system transmits single frequency either uniquely, as a series of frequency steps, or as an impulse. The amplitude and phase of the return signal is measured and the resulting data can be converted to the time domain. The frequency domain has a higher SNR due to a higher and more uniform spectral density of the radiated signal. It allows to use a much larger frequency bandwidth than the time-domain approach. On the other hand, the frequency-domain approach requires more bulky and more expensive equipment and a larger measurement time [3].

3.8.1 Time frequency analysis

Since its introduction in the early nineteenth century, the Fourier transform has become one of the most widely used signal-analysis tools across many disciplines of science and engineering. The basic idea of the Fourier transform is that any arbitrary signal (of time, for instance) can always be decomposed into a set of sinusoids of different frequencies. The Fourier transform is generated by the process of projecting the signal onto a set of basis functions, each of which is a sinusoid with a unique frequency. The resulting projection values form the Fourier transform (or the frequency spectrum) of the original signal. Its value at a particular frequency is a measure of the similarity of the signal to the sinusoidal basis at that frequency. Therefore, the frequency attributes of the signal can be revealed via the Fourier transform. In many engineering applications, this has proven to be extremely useful in the characterization, interpretation, and identification of signals.

Joint time-frequency transforms are used for the purpose of characterizing the time-varying frequency content of a signal. The best-known time-frequency representation of a time signal dates back to Gabor and is known as the short-time Fourier transforms (STFT). It is basically a moving
window Fourier transforms. By examining the frequency content of the signal as the time window is moved, a two dimensional time-frequency distribution called the spectrogram is generated. The spectrogram contains information on the frequency content of the signal at different time instances. One well-known drawback of the STFT is the resolution limit imposed by the window function. A shorter time window results in better time resolution, but leads to worse frequency resolution, and vice versa.

3.8.2. The short time Fourier transform (STFT)

The most standard approach to analyze a signal with time-varying frequency content is to split the time-domain signal into many segments, and then take the Fourier transform of each segment. This is known as the STFT operation and is defined as

\[ \text{STFT}(t, \omega) = \int s(t') w(t' - t) \exp \{-j\omega t'\} dt' \quad (3.20) \]

This operation differs from the Fourier transform only by the presence of a window function \( w(t) \). As the name implies, the STFT is generated by taking the Fourier transform of smaller durations of the original data. Alternatively, we can interpret the STFT as the projection of the function \( s(t') \) onto a set of bases \( w^*(t' - t) \exp\{j\omega t'\} \) with parameters \( t \) and \( \omega \). Since the bases are no longer of infinite extent in time, it is possible to monitor how the signal frequency spectrum varies as a function of time. This is accomplished by the translation of the window as a function of time \( t \), resulting in a 2D joint time-frequency representation \( \text{STFT}(t, \omega) \) of the original time signal. The magnitude display \( |\text{STFT}(t, \omega)| \) is called the spectrogram of the signal. The definition of the STFT can also be expressed in the frequency domain by manipulating the above equation with the result

\[ \text{STFT}(t, \omega) = \frac{1}{2\pi} \exp\{-j\omega t\} \int s(\omega') W(\omega - \omega') \exp\{j\omega t\} d\omega' \quad (3.21) \]

Here \( W(\omega) \) is the Fourier transform of \( w(t) \). The dual relationship between the above two equations is apparent (i.e., the time-frequency representation can be generated via a moving window in time or a moving window in frequency). In addition, I see the following observations: Signal components with durations shorter than the duration of the window will tend to get smeared out i.e., the resolution in the time domain is limited by the width of the window \( w(t) \). Similarly, the resolution in the frequency domain is limited by the width of the frequency window \( W(\omega) \). The
window width in time and the window width in frequency are inversely proportional to each other. Therefore, good resolution in time (small time window) necessarily implies poor resolution in frequency (large frequency window). Conversely, good resolution in frequency implies poor resolution in time. The window width in each domain remains fixed as it is translated. This results in a fixed resolution across the entire time-frequency plane.
CHAPTER FOUR

Methodology
In this thesis, the following basic steps were followed based on the theoretic considerations.

a. Experimental Data collection
b. Processing of the Collected data

Data from [1] is used as a starting point, the data [1] used a 1.5 GHz GPR system, and the system collects 10 scans per cm, each composed of 512 samples with 16 bits per sample and a range of 12 ηs. The antenna had a survey wheel, which suspends the antenna at a height of 2 cm above the ground for his data collection. The receiver and transmitter antennas are shielded, that is, direct coupling and interference from the surrounding systems is negligible. He setup an experiment of two true targets M14(42mm x 52 mm) and PMN1(50mm x 120 mm), pieces of rock and wood as random clutters, by placing targets at a depth 2.5 to 5 cm below the ground surface.

The M14 and PMN1 materials were composed of PVC casing, paraffin wax filling and small metal parts and the site was a naturally clay-loom mixture soil under a vegetation has been used for the experiment.

The first step in processing of collected data, offset removal that has been caused by unwanted DC signal shift from the mean value. To realize offset removal on matlab program by subtracting the spatial mean of Bscan from the whole Bscan.

The second step is noise removal. Here noise of different characteristics can be experienced and the noise removal techniques employed takes this fact into account. The matlab realization done by employing exponential moving average or weighted moving average function.

The third step is to remove background clutter which accounts for most of the energy received at the receiver. a matlab program done by two possible ways, either by subtracting the whole mean or median of the data from each Bscan; or by calculating the running mean or running median of all traces.

Finally the pre-processed data has been processed further to give a more revealing picture of the buried mine, by analyzing a signal with time-varying frequency content and splitting the time-
domain signal into many segments, and then take the Fourier transform of each segment known as the short time Fourier transform.
CHAPTER FIVE

Results and Discussion

5.1. Collected data

In this thesis work, an image was first plotted from the data [1]. The horizontal axis of the image describes the horizontal distance covered in millimeter scale. The image at this point is a collection of the wanted targets, channel noise, background reflection, unwanted targets (clutter). The wanted targets cannot be easily identified. As can be seen on the image of the measured data, most of the signal transmitted by the transmitter antenna of the GPR will be reflected by the ground at the air ground interface. Once the signal enters the ground, there are many reflections from different clutters in the ground due to subsurface dielectric differences. From the color scale indicated, the higher reflection occurs when there is a greater difference in dielectric properties i.e. air-ground interface and at this moment the energy concentration is higher but for the medium reflection indicated there is small changes in dielectric properties i.e. ground and targets and non target objects. The low reflection scale indicates slight or no changes in dielectric properties.
5.2. Processing of the collected data

After offset removal the mean value of an A-scan is close to zero. This assumes that the amplitude probability distribution of the A-scan is symmetric about the mean value. The short time mean value may vary over the time duration of the A-scan. As can be seen from my simulation results on figure 5.2, there are some improvements on the image of the data after removal of the offset.
Figure 5.3. Noise removed Bscan using exponential Moving Average techniques

To remove the noise incurred during measurement by using offset removed data as an input to a weighted Moving Average noise removal technique. After removal of the noise some improvements are shown as in the figure.5.3.
Once the offset and noise have been removed, the next step is to remove the background. Considering the noise removed Bscan using Exponential Moving average technique as an input to the background removal block. A MATLAB code using running mean for background noise removal techniques was considered and a better result seen as on Figure 5.4.

Figure 5.4 background removed Bscan using Running Mean technique
5.4. The time frequency analysis

Using the time frequency signal processing for the Running Mean data which has been pre-processed. As can be depicted from the figure 5.3 above, the time-frequency analysis gives a sound idea about the energy distribution of the landmine using time and frequency axis. PMN1 and M14 are the true targets. A high resolution image of the PMN1 which is made up of a plastic can containing a small metal and filled with wax can be seen on the picture. The M14 which is of lower dielectric coefficient than the PMN1 as shown on the figure 5.5 as an image with a little bit lower energy concentration. The output clearly shows the improvements made by STFT but there is also some deviation on the left side of the image created due to the higher resolution.

Figure 5.5. Image of Running Mean data using STFT of Hann window size 49
Applying the discrete STFT matlab code on the RunMn data in the pre-processing step, there are a number of options to choose from in calculating the discrete STFT. These are using windows of different types like hann window, hamm, rect, triag, blackman, bartlet window etc. and these windows can be of different sizes varying from small to large. For comparison, considering STFT image of window sizes of 49 and 100 using a hann window and a sampling frequency of 1000Hz. For the same window type of different window sizes, the Discrete STFT shows different properties. A more revealing picture of the energy concentration is found with smaller values of window size. When the size of window is large, it becomes difficult to identify where exactly most of the energy in the data is concentrated.
CHAPTER SIX

Conclusion and Recommendation

Landmines have been a global concern for centuries and still are. Ethiopia is one of the nations highly affected by landmines. Many landmine detection and demining techniques are being employed worldwide. These include demining by manual means of detection, metal detection, biological detection, GPR detection and etc. Each of these techniques has its own merits and demerits.

Application of GPR system for landmine detection is new area of research which is showing promising results from time to time and it needs to be well researched. There are four key elements of a GPR system for landmine detection. These are: the transmitter, the receiver, the data processor and the display blocks. Impulse input is given to the transmitter antenna and the antenna radiates an impulse signal down into the ground. The transmitted signal will definitely be exposed to noise on the air and it will be into the ground. There will be multiple layer reflections of the transmitted signal from the ground back to the air. The receiver collects all reflections from the different layered surfaces. The received reflections contain the sum of signals reflected from the wanted targets, noise on the air, receiver and transmitter antenna cross talk signals, reflections from the air ground interface, and different mine like clutters in the ground. Therefore there has to be a digital signal processing technique that can help boost the required target shape and size information.

There are a number of preprocessing techniques for offset removal, noise removal and clutter reduction. The preprocessed data needs to be further processed with advanced signal processing techniques so as to give a more revealing shape and size information or energy concentration of the landmine. One of the advanced signal processing techniques is time-frequency analysis which give information about the energy concentration of the landmine.
References


[31] B. Suksmono Andriyan et al., "Interpretation Target Pattern of Burried Basic Object on Surface Ground Penetrating Radar," Journal, vol 1, number 1, 2009