UWB radar technology for the detection and identification of buried targets

Eumw2011-The 2011 Defence and Security Forum Morning session 10:40
Summary

• This presentation will review the application of UWB radar technology for the detection and identification of buried targets.

• The physics of propagation and the properties of typical materials will be presented as a background to system design considerations.

• The presentation will review the types of radar signal modulation and their system implementation as well as impact on performance and system efficiency.

• Examples of various applications will be presented
Synopsis

- **Introduction**
- **Targets**
- **Environment**
- **Physics of propagation**
- **Radar systems**
- **Antennas**
- **Signal Processing**
- **Summary**
Relationships

SPEED REQUIREMENTS

OUTPUT POWER

ANTENNA GAIN

SYSTEM LOOP GAIN

PD and FAR performance

PROCESSOR GAIN

BANDWIDTH

SYSTEM NOISE

SYSTEM INTERNAL CLUTTER

TARGET DRI

TARGET PARAMETERS

SYSTEM LOOP GAIN

GROUND PROPAGATION PARAMETERS

EXTERNAL NOISE AND CLUTTER

TEMPERATURE

RESOLUTION

BANDWIDTH

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Background

- Ground penetrating radar (GPR) is an electromagnetic technique for the location of objects or interfaces buried beneath the earth's surface or located within a visually opaque structure.

- Landmine or IED detection is an example of a relatively successful application of GPR, which is a special class of ultra-wideband (UWB) radar and can radiate energy in the range of frequencies from a few MHz up to 10GHz with a bandwidth of up to a decade, but more usually 2-3 octaves.

- The typical average radiated power, integrated over the band of interest, may be in the order of a milliwatt, but the power per Hz may be as low as picowatts.

- For landmine detection it is important that the radiated power is lower than that required to initiate some types of fuse.
**Background**

- Most GPR systems are operated so that the landmine, which is buried within a lossy dielectric, may be only a few wavelengths from the aperture of the antenna.

- Most GPRs for landmine detection operate in a region where the wavelengths radiated are greater than, or in the same order of magnitude as the dimensions of the landmine.

- This is between the Rayleigh and Mie (or resonance) region of the landmine dimensions and is quite unlike conventional radar systems where the target dimensions are much larger than the wavelength of the incident radiation, i.e. the optical region.

- The total path losses within a few wavelengths may be as much as 100dB depending on the material and as GPR systems do not have a total loop gain much in excess of 120dB the designer has a major challenge to detect landmines signatures within very short ranges of typically 20ns. (Note that time domain systems have a lower loop gain)
Path losses versus range

- Path loss in dB
- Range in metres

Levels:
- Low
- Medium
- High

dB Levels:
- 0 dB
- -50 dB
- -100 dB

0 m - 1 m
Background

- GPR can be operated so that the antenna is very close to the ground surface and target such that the energy transfer is predominantly either induction or quasi-stationary, (the near field) or can be operated such that the energy transfer is in the far field region.

- There is some evidence that propagation into the ground when the antennas are closely coupled may be due to evanescent waves.

- GPR encounters extremely high levels of clutter at short ranges and this as well as signal/noise ratio is its major technical challenge.
• The power radiated is subject to limits on the maximum transmitted power spectral density [PSD dBm/Hz] on the equivalent isotropically radiated power [EIRP] peak emissions.
Handheld systems

- Handheld GPR systems use separate, man-portable, transmit and receive antennas, which are placed just above the surface of the ground.

- These moved in a known pattern over the surface of the ground under investigation. This generates real time data.

- By systematically surveying the area in a regular pattern, a radar image of the ground can be built up.
Hand held operation

• Alternatively, the GPR may be designed to provide an audible warning of target presence while the antenna is moved over a target.

• Successful operation of a handheld GPR system is based on the skill of the operator in adjusting the sweep rate and antenna height to optimise the spatial positioning of the radar to obtain maximum signal.

• Multiple passes over the target are often used to confirm detection
Vehicle systems

- Vehicle based or airborne systems use much larger arrays of antennas to illuminate a swathe of the ground surface ahead of the platform and rely on the movement of the vehicle to create the down track data.

- The data gathering is single pass

- Both the down track and cross track data may be processed using SAR techniques.

- Where the antenna elements are relatively close to the ground, the path losses encountered by off nadir elements may limit the SAR gain that can be achieved.

- As the array elements are generally fixed in position, changes in ground topography in both cross track and down track affect the path propagation and influence the type of signal processing that can be applied.
16 channel radar system
Synopsis

- Introduction
- **Targets**
- Environment
- Physics of propagation
- Radar systems
- Antennas
- Signal Processing
- Summary
# Explosive parameters

<table>
<thead>
<tr>
<th>Substance</th>
<th>Name</th>
<th>Molecular Weight</th>
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<td>AN</td>
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<td>Nitroglycerin</td>
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<td>1.59</td>
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</tr>
</tbody>
</table>
Radar cross section

• Where a target is a dielectric the RCS is changed by the properties of the intrinsic dielectric and if the target is embedded in soil the properties of that material.

• Where a target is buried in the ground, the effect of the RCS on the radar range equation, which assumes a point source scatterer, needs to be considered. The radar range equation may need adjusting for the different types of targets as shown below as the nature of the target influences the magnitude of the received signal. The following approximate relationships apply for targets, which extend across the zone illuminated by an antenna (i.e. its footprint).

  – Point scatterer \([\text{Target depth}]^{-4}\)
  – Line reflector \([\text{Target depth}]^{-3}\)
  – Planar reflector \([\text{Target depth}]^{-2}\)

• The RCS will vary with angle and one phenomena which is often seen is a scintillation in the target RCS as a function of angular position.
The main regions of the RCS are the Rayleigh region, where the RCS rises as the fourth power of the sphere radius for $k_o a < 0.7$, the Resonance region between $0.7 < k_o a < 10$ and the Optical region where $k_o a > 10$.

The oscillations in the resonance region are due to the creeping wave adding and subtracting in phase with the specular reflection as a function of sphere circumference.
Target scattering

• Unprocessed GPR images often show "bright spots" caused by multiple internal reflections within the target as well as a distortion of the aspect ratio of the image of the target caused by variations in the velocity of propagation.

• Symmetrical targets, such as spheres, cause migration of the reflected energy to a hyperbolic pattern. GPR images can be processed to compensate for these effects and this is usually carried out off-line.

• A GPR can be designed to detect specific targets by means of polarised radiation.
Radar images – metallic targets

Ground surface

Metallic sphere
MINES – AP MINES

- Courtesy GICHD
MINES – AT MINES

- TM-57 metallic landmine
- TM-62 P2 minimum metal antitank landmines (GICHD)
IMPROVISED EXPLOSIVE DEVICES
SYNOPSIS

• Introduction
• Targets
• **Environment**
• Physics of propagation
• Radar systems
• Antennas
• Signal Processing
• Summary
MINES – AP mines – PMA2 – PMN6

Cambodia PMN6 AP mine in Kamrieng minefield shown uncovered prior to detonation

PMA2 AP landmine in Bosnia

Cambodia Banteay Ta Oy 9 minefield
REPUBLIC OF SERBSKA
LEBANON ISRAELI MINEFIELD
TRAPEING BEI VILLAGE SCHOOL
Afghanistan
SYNOPSIS

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FIELD CONSIDERATIONS

- **Proximal systems**
  - GPR systems operated close < 5cm to the ground surface, usually with a zero angle of incidence

- **Close in systems**
  - GPR systems operated 0.5-1m from the ground surface, usually with a zero angle of incidence

- **Standoff systems**
  - GPR systems operated >5m from the ground surface usually at a slant angle
Propagation issues

• The GPR image of a target is very different to its optical image because the wavelengths of the illuminating radiation are similar in dimension to the target. This results in a much lower definition in the GPR image and one that is highly dependent on the propagation characteristics of the ground.

• The beam pattern of the antenna is widely spread in the dielectric and this degrades the spatial resolution of the image, unless corrected. Refraction and anisotropic characteristics of the ground may also distort the image.

• For some longer-range systems, synthetic aperture techniques processing techniques are used to optimise the resolution of the image.
• The impedance of a buried target must be different from the surrounding soil or material for a reflection to occur and its relative dielectric constant should be significantly less or greater than the host soil.

• Landmines with an explosive whose relative dielectric constant is in the range of 2.3 to 2.8 will become difficult to detect in dry desert soils whose relative dielectric constant is in the same range.

• Typically, most soils exhibit a relative dielectric constant, which ranges between 2 to 25.

• Fresh water has a relative dielectric constant of approximately 80 and it is quite feasible to detect targets in fresh water or soils saturated in fresh water.

• Salt water completely attenuates radar signals.
Fields

Electrostatic field terms \( r^{-3} \)
Induction field terms \( r^{-2} \)
Radiation field terms \( r^{-1} \)

Proximal operation may include contributions from the electrostatic and induction fields

Near field – far field boundary = \( \frac{\lambda}{2\pi} \)

At 1GHz = 4.77cm

Vertical axis units = \( Z_0 I d l \pi \sin(\theta)/\lambda^2 \)

Horizontal axis units = \( \lambda/2\pi \)
Far field radar range equation – free space, point scatterer, single frequency

\[ P_r = P_t \times G_t \times \frac{1}{4\pi \cdot r^2} \times \sigma \times \frac{1}{4\pi \cdot r^2} \times A_e \]

If the transmit and receive antennas and their impedances are identical then the receiver voltage

\[ V_r = V_o \times \frac{A_e}{\nu} \times \frac{1}{\sqrt{4\pi \cdot r^2}} \times \sqrt{\sigma} \]

\[ V_r = \frac{V_o}{\tau} \times \frac{1}{c} \times \frac{A_e}{\sqrt{4\pi}} \times \frac{1}{r^2} \times \sqrt{\sigma} \]
However the propagation path is through a lossy dielectric and the transmission coefficients and target reflection coefficients reduce the received signal, hence:

\[
V_r = \frac{V_o}{\tau} \times \frac{1}{c} \times \frac{A_e}{\sqrt{4\pi}} \times \frac{1}{r^2} \times \sqrt{\sigma} \times \tau_{ag} \times \tau_{ga} \times \sigma_t \times e^{-k \cdot 2 \cdot r}
\]

Key terms are as shown circled

This expression can be used to derive the signal to system noise ratio and using the error function the probability of detection.
PD versus range  1GHz

Radiated voltage = 2 V
Centre frequency = 1 GHz
Pulse bandwidth = 2 GHz
Antenna aperture = 0.071 m²
Noise figure = 9 dB
Signal averaging = 5
Material relative dielectric constant = 9
Material loss = 27 dBm⁻¹
Target relative dielectric constant = 2.2
Target diameter = 10, 20, 30, 40 and 50cm
Spatial resolution

- Radar image of buried mines, Impulse duration 1ns, Image 1m by 0.65m depth 180-220mm

- Radar image of buried mines, Impulse duration 0.5ns, Image 1m by 0.65m depth 180-220mm
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## Typical radar system specification

<table>
<thead>
<tr>
<th>Radar parameter</th>
<th>Value</th>
<th>Units</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>2</td>
<td>GHz</td>
<td>Idealised</td>
</tr>
<tr>
<td>Centre frequency</td>
<td>1.5</td>
<td>GHz</td>
<td></td>
</tr>
<tr>
<td>Integration time</td>
<td>1.10^{-3}</td>
<td>seconds</td>
<td></td>
</tr>
<tr>
<td>Antenna gain</td>
<td>10</td>
<td></td>
<td>Idealised</td>
</tr>
<tr>
<td>Noise figure</td>
<td>5</td>
<td></td>
<td>Idealised</td>
</tr>
<tr>
<td>SN threshold</td>
<td>14</td>
<td>dB</td>
<td></td>
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<td>Ambient temperature</td>
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<tr>
<td>Range window</td>
<td>20.10^{-9}</td>
<td>seconds</td>
<td></td>
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<tr>
<td>Radiated power spectral density</td>
<td>-40</td>
<td>dBm / MHz</td>
<td>ETSI specification</td>
</tr>
<tr>
<td>Total mean power</td>
<td>-5</td>
<td>dBm</td>
<td>derived</td>
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<tr>
<td>Spatial sampling frequency</td>
<td>444</td>
<td>Hz</td>
<td>1cm at 10kph</td>
</tr>
</tbody>
</table>
Time Domain radar systems

1MHz CLOCK

TIME DELAY

Pulse generator

TRANSMIT ANTENNA

19/02/2012
SEQUENTIAL SAMPLING

Slow ramp (N*A*P)
Fast ramp (1ms)

N = number of samples
A = number of averages
P = pulse repetition interval

Incremental sampling
P + N_i x 50ps

Down sampled RF signal
16 Channel Radar system
FMCW radar systems

Master oscillator
10KHz
Antenna
Mixer
IF Highpass filter
IF amplifier
A to D convertor
then to FFT
RF power amplifier
Local oscillator
Discriminator
Error signal
VCO
Sweep modulator
Driving signal
Multiplier
Mixer
Antenna
Sweep modulator
Master oscillator
10KHz
Error signal
Driving signal
FREQUENCY TIME WAVEFORMS

- TBD

\[
\begin{array}{c}
\text{frequency} \\
0 & 0.1 & 0.2 & 0.3 & 0.4 \\
\end{array}
\]

\[
\begin{array}{c}
\text{relative time} \\
0 & 5 & 10 & 15 & 20 & 25 & 30 & 35 & 40 & 45 & 50 \\
\end{array}
\]

- transmit signal
- receive signal
SWEEP NONLINEARITY

- TBD

---

transmitted signal

delayed signal

---

signal in dB

relative IF frequency

---

signal in dB

relative IF frequency
SOURCE PURITY

- TBD

![Graph of signal in dB over relative time](image-url)
SFCW radar systems

CONTROL

INPUT

ICFFT(w)

DATA OUTPUT

CIRCULATOR

SIGNAL SOURCE

MIXER

ALIASING FILTER

ANTENNA

DATA OUTPUT

+ -

CALIBRATION DATA

19/02/2012

2011 DEFENCE AND SECURITY FORUM
Step frequency radar
Radar systems

- In both cases the difference frequency is composed of contributions from all targets up to and beyond the ambiguous range given by

\[ R_{\text{amb}} = \Delta R \cdot N \]

- where
  - \( \Delta R = \) range resolution
  - \( N = \) number of frequency steps

- The radar radiates a sequence of \( N \) frequencies and the amplitude and phase of the received and down converted signal is stored. A complex Inverse Fast Fourier Transform or equivalent algorithm is then used to produce a time domain version of the reflected signal.
Radar systems

- The range to each target can be determined by performing a suitable transform with respect to the steps of frequency. The received signal can be expressed as:

\[
E_n = \sum_{k=0}^{N-1} \frac{\sigma_k E_T}{r_k^2} \exp \left\{ j 4\pi \left( \frac{f_0 + n\Delta f}{r_k} \right) r_k \right\} / c
\]

- where
  - \( r_k \) = distance to the kth target
  - \( \sigma_k \) = target scattering coefficient
  - \( f_0 \) = start frequency
  - \( \Delta f \) = frequency increment
  - \( n \) = number of frequency steps
Noise or PRC radar

Carrier frequency oscillator

Bandpass filter

Mixer

Time delay = unambiguous range

Variable time delay

RF Power Amplifier

Multiplier

Circulator

Antenna

Noise source

Output
Radar systems

• Noise modulated radar offers some very attractive possibilities to the designer of GPR systems.

• The radiated power is evenly spread throughout the spectrum and the receiver is less susceptible to interference.

• However until recently such systems were relatively rare. Developments over the last few years are changing that situation and more efforts are being put into the development of noise radar systems.
Radar systems

- The basic principle of operation of noise radar is that of a correlator. The radar transmits a noise signal and the received signal is a time delayed version $t_s$ of the transmitted signal. In the receiver the transmitted signal is used via a variable delay $t_v$ to cross correlate the received signal.

- The received signal can be written as

$$v(r) = \sigma_t v(t - T_s) + vc(t)$$

- $v(t-T_s) =$ the transmitted signal reflected by the target at time $T_s$
- $\sigma_t =$ target reflectivity
- $vc(t) =$ reflections from clutter

- The cross correlation can be written as

$$R(\tau) = \int_{0}^{T_i} v(r) \cdot v(t - T_s) \, dt$$

- Where $T_i$ is the integration time
Radar systems

- Receiver output from
- Targets decreasing in amplitude
- Targets close together
Radar systems

• Assuming identical
  – radiated power spectral density
  – receiver integration times
  – antenna gains
  – receiver noise figures

• Consider following cases
  – Sequential sampling radar
  – FMCW radar
  – Step frequency radar
  – Noise radar
## SUMMARY

<table>
<thead>
<tr>
<th>Radar</th>
<th>Radar</th>
<th>Dynamic range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td></td>
<td>121dB</td>
<td>Matched receiver, T=300K F=5, G=10, S/N=25</td>
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</tbody>
</table>

### REDUCING PARAMETERS

<table>
<thead>
<tr>
<th>Time domain</th>
<th>Sequential sampling</th>
<th>88dB</th>
<th>Antenna coupling and ringdown, RX noise figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency domain</td>
<td>Stepped frequency</td>
<td>85dB [121dB]</td>
<td>Antenna coupling and ringdown, RX noise figure, duty cycle, sample window sidelobes</td>
</tr>
<tr>
<td>Frequency domain</td>
<td>FMCW</td>
<td>84.5dB [121dB]</td>
<td>Antenna coupling and ringdown, RX noise figure, sample window sidelobes and linearity</td>
</tr>
<tr>
<td>Noise</td>
<td>Noise</td>
<td>121dB</td>
<td>Antenna coupling and ringdown, RX noise figure, cross correlation window sidelobes</td>
</tr>
<tr>
<td>Noise</td>
<td>PRC</td>
<td>105dB</td>
<td>Antenna coupling and ringdown, RX noise figure, cross correlation window sidelobes and sequence</td>
</tr>
</tbody>
</table>
SYNOPSIS

- Introduction
- Targets
- Environment
- Physics of propagation
- Radar systems
- Antennas
- Signal Processing
- Summary
Antenna types

• The two general types of antenna that are useful to the designer of surface penetrating radar fall into two groups:

• Non-dispersive antennas and dispersive antennas.

• Examples of non-dispersive antennas are the TEM Horn, the bicone, the bow-tie, the resistive, lumped element loaded antenna or the resistive, continuously loaded antenna.

• Examples of dispersive antennas that have been used in surface penetrating radar are the Exponential spiral, the Archimedean spiral, the logarithmic planar antenna, the Vivaldi antenna and the exponential horn.
Antenna development
Time domain antenna

- A typical antenna used in an impulse radar system would be required to operate over a frequency range of a minimum of an octave and ideally at least a decade, for example, 100 MHz - 1 GHz.

- The input voltage driving function to the terminals of the antenna in an impulse radar is typically a Gaussian pulse and this requires the impulse response of the antenna to be extremely short.

- The main reason for requiring the impulse response to be short is that it is important that the antenna does not distort the input function and generate time sidelobes. These time sidelobes would obscure targets that are close in range to the target of interest, in other words the resolution of the radar can become degraded if the impulse response of the antenna is significantly extended.

- All of the antennas used to date have a limited low frequency performance unless compensated and hence act as high pass filters, thus the current input to the antenna terminals is radiated as a differentiated version of the input function.

- In general it is reasonable to consider that the far field radiated electric field is proportional to the derivative of the antenna current.
Dipole

- As shown two current and charge impulses will travel along the antenna elements until they reach each end. At the end of the antenna the charge impulse increases while the current collapses. The charge at the end of the antenna gives rise to a reflected wave carried by a current travelling back to the antenna feed terminals. This process continues for a length of time defined by the ohmic losses within the antenna elements. The electric field component $E_z$ is given by Kappen and Monich and must equal zero at the surface of the antenna.

$$E_z = - \frac{1}{4 \pi \varepsilon_0} \int_{l_1}^{l_2} \left\{ \frac{1}{c} \frac{dl}{dt} + \frac{\partial q}{\partial z'} \right\} \frac{1}{r} dz'$$
Unloaded dipole
Wu King profile

- The resistivity taper profile for a resistively loaded antenna of the Wu King type has the form given by Rao (1991)

\[ R(z) = \frac{R_0}{1 - \frac{z}{H}} \]

[Graph showing the resistivity profile of a 200mm element]
• The parameters of the antenna such as input resistance, resistivity profile etc., have all been extensively treated in a classic paper by Wu and King (1965). Lumped element resistors can be placed at a distance l/4 from the end of the antenna, Altschuler (1961) and a travelling wave distribution of current can be produced by suitable values of resistance. The distribution of current varied almost exponentially with distance along the element. Instead of lumped element resistors a continuously distributed constant internal impedance per unit length can be used.
Travelling Wave Antennas

- Antennas that can support forward travelling TEM wave are often called TEM horns. In general such antennas consist of a pair of conductors either flat, cylindrical or conical in cross section forming a V structure in which radiation propagates along the axis of the V structure. Although resistive termination is used, this type of antenna has a directivity in the order of 10-15 dB, hence useful gain can still be obtained even with a terminating loss in the order of 3 dB to 5 dB.
Vivaldi antennas

- The Vivaldi antenna consists of a diverging slot-form guiding conductor pair as shown in Figure 25. The curve of one of the guiding structures follows the equation.

- Radiation is produced by a non-resonant travelling wave mechanism by waves travelling down a curved path along the antenna. Where the conductor separation is small, the travelling wave energy is closely coupled to the conductor but becomes less so as the conductor separation increases.

- The Vivaldi antenna provides gain when the phase velocity of the travelling wave on the conductors is equal or greater than that in the surrounding medium.
Surface penetrating radar presents the system designer with significant restrictions on the types of antennas that can be used. The propagation path consists in general of a lossy, inhomogeneous dielectric, which, in addition to being occasionally anisotropic, exhibits a frequency dependent attenuation and hence acts as a low pass filter. The upper frequency of operation of the system, and hence the antenna, is therefore limited by the properties of the material.

The need to obtain a high value of range resolution requires the antenna to exhibit ultra-wide bandwidth, and in the case of impulsive radar systems, linear phase response.

The requirement for wide bandwidth and the limitations in upper frequency are mutually conflicting and hence a design compromise is adopted whereby antennas are designed to operate over some portion of the frequency range 10 MHz to 5 GHz depending on the resolution and range specified.
Summary

- Antennas for GPR generally have
  - Low gain
  - Poor sidelobes and backlobes
  - Specific requirements in terms of bandwidth
  - Specific requirements in terms of impulse response
  - Are modified when in proximity to the ground
  - Require linear phase for time domain systems
SYNOPSIS

• Introduction
• Targets
• Environment
• Physics of propagation
• Radar systems
• Antennas
• **Signal Processing**
• Summary
A scan processing

\[ f_r(t) = f_s(t) * f_{at}(t) * f_c(t) * f_{gf}(t) * f(t) * f_{gr}(t) * f_{ar}(t) + n(t) \]

* = convolution

where

\begin{align*}
  f_s(t) &= \text{signal applied to the antenna} \\
  f_{an}(t) &= \text{antenna impulse response} \\
  f_c(t) &= \text{antenna cross coupling response} \\
  f_{gd}(t) &= \text{ground impulse response (d denotes direction)} \\
  f_t(t) &= \text{impulse response of target} \\
  n(t) &= \text{noise}
\end{align*}
Processing methods

- **A-scan data processing**
  - Unprocessed data
  - Aligned data
  - Average data
  - Background removal
  - Surface tracking
  - Path loss compensation
  - Wavelet deconvolution

- **B-Scan processing**
  - 2-D Migration
  - 2-D SAR processing
  - 2-D Pattern Template matching

- **C-scan processing**
  - 2/3-D Migration
  - 2/3-D SAR processing
  - 2/3-D Pattern Template matching
Data processing

- A scan data
  - Pre-processing and data smoothing, ground surface removal
  - Time series analysis
  - Frequency domain analysis STFT, wavelets,
  - Neural network processing
  - Principal component analysis
  - Deconvolution techniques
  - Singularity identification
  - Template matching

- B Scan data and C Scan data
  - Preprocessing and data smoothing
  - Inverse scattering filtering -- migration, SAR, etc
  - Deconvolution techniques
  - Template matching
  - Image processing and filtering
AT mine image TMA-3
2 GHz Antenna 20 mm from surface - AP Mine in sand, flush with surface

Marker interval: 1.0s

Estimated Depth (m)
STFT classification

Animal burrow and stone false alarm targets

PMA3 and VS50 AP landmines

Frequency 0-10 GHz

Time in ns 0-12.5ns
SINGULARITY analysis

The basis of the technique is that every signature will possess a unique resonant characteristic. Hence every target can be identified in terms of its resonant characteristic. Waveforms can be modelled by a series of exponentials in which the amplitude and delay constant are variable, hence

\[ P(t) = \sum_{i} a_i e^{\alpha_i t} \]

A discretised version of the above gives

\[ \alpha_n = \sum_{n=1}^{N/2} A_n \exp j\phi_n \exp (\alpha_n + j\omega_n) n\Delta t \]

where each parameter is given as follows

\( A_n = \) Amplitude
\( \phi_n = \) phase
\( \alpha = \) damping factor
\( \omega = \) frequency
There are two realisations of the Prony method, the classical or the eigenvalue method and details of these are discussed in Chan et al (1981a). Prony's method is inherently an ill conditioned algorithm and is highly sensitive to noise and estimates of the number of poles at present in the data. The eigenvalue method was found to give better results although highly sensitive to the choice of the parameters. In addition a wide dynamic range is needed to cater for both the early and late time portions of the wavelet.

See AP mine analysis from (O. Lopera)
The migration process essentially constructs the target reflector surface from the record surface. The migration technique has been much developed in acoustic, seismic and geophysical engineering and was originally developed in two-dimensional form by Hagedoorn (1954). More recent developments employ wave equation methods such as Kirchoff migration, finite difference migration and frequency wave-number migration.
A relatively straightforward geometric approach can be used in the two-dimensional case of a material with known constant velocity. If the measured time to the point reflector is \( t \) then the distance to the point reflector is given by \( z = \frac{vt}{2} \). At any position along the \( x \) axis the distance \( z \) is also given by

\[
z_i = \sqrt{(x_i - x_0)^2 + z_0^2}
\]

This equation shows that the measured wavefront appears as a hyperbolic image or a curve of maximum convexity. The geometric migration technique simply moves or migrates a segment of an A-scan time sample to the apex of a curve of maximum convexity. The hyperbolic curve needs to be well separated from other features and a good signal to noise ratio is needed.
Migration techniques (Scheers)

Oblique AP landmine 30 degrees

- **Raw data**
- **migration by deconvolution**
- **migration by Kirchoff**

AP landmine 5cm depth in gravel

- **Raw data**
- **migrated data planar cut**
Wave field extrapolation techniques are based on three methods; the Kirchoff summation approach, the plane wave method (k - f method) and the finite difference method.

The general process of imaging of such data consists of two operations.

The first consists of a wave field extrapolation whereby using a scalar wave equation, the recorded data are transformed into a new data series which represent simulated recordings at new positions of the measurement plane.

The second operation of imaging generates the data around the zero time travel position of the simulated recording related to planes within the B-scan or C-scan.
Reverse Time Migration
KTN John Schofield

Start: $B$-scan $R(r_m, 0, t)$

Reverse Time

$R(r_m, 0, -t)$

Introduce B-scan as time varying sources back into the object space

$R(r_m, z, -t)$

Back propagate the sources from the B-scan back into the object space using FDTD

$R(r_m, z, -t + \delta t)$

Use FDTD to reverse the data until $t = 0$ which will give us our wavefront reconstruction

Stop: $R(r_m, z, 0)$
Data pre processing
Reverse Time Migration processing

B Scan after Focusing

Window Metric Results - Normalised cutoff 0.5

Response Number vs Distance

Distance vs Response Number
Reverse Time Migration detection

- Thresholded pre RTM

- Thresholded post RTM
SYNOPSIS

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• Summary
Summary

• UWB GPR is an electromagnetic technique for the location of objects or interfaces buried beneath the earth's surface or located within a visually opaque structure.

• Landmine and IED detection is an example of a relatively successful application of GPR, which is a special class of ultra-wideband (UWB) radar.

• The requirement for portability means that it is normal to use electrically small antennas, which consequently results in low gain and associated broad polar radiation patterns. This requires robust signal processing techniques to compensate for the high clutter levels.

• The radar system loop gain rarely exceeds 120dB and is more typically 80dB. The short time ranges of circa 10-30ns and high dynamic range over this period are a design challenge.

• The wide variability of the soil parameters and target scattering also provide a major design challenge.
Summary

• The end user requires hand held radar systems need to be compact, light weight and low power consumption [≤ 2W]

• Vehicle based systems have less stringent size, weight and power requirements, but the single pass operation tasks the signal processing requirements more than the hand held radar.

• While considerable research into target recognition techniques has been carried out, the variability of the soil and target parameters has challenged the development and implementation of robust and reliable signal processing methods.

• While UWB GPR technology can now be considered mature, there are still considerable opportunities for reduction of size weight and power as well as improvements in detection performance as well as reduction of false alarms
Thank you for your attention

Questions