Brad Artman

Spring Review 2005
Passive Spy vs. Spy
Passive Spy vs. Spy
Passive Spy vs. Spy

SS2's continuous wave (CW) multistatic technology provides an all-weather, passive surveillance capability through the exploitation of radiant energy from commercial FM radio stations. The transmitted signals from these illuminators are scattered from airborne targets and received by the SS2 target antenna (a horizontal linear phased array antenna in the current implementation). Separate, reference antennas also receive the direct path signals from the FM transmitters. High dynamic-range receivers are used to accommodate the dynamic range requirements for receiving direct and scattered signals simultaneously.

Basic Concept of Silent Sentry Operation

Continuous coverage of 90 degrees azimuth is achieved through the use of innovative digital signal processing algorithms. Delay (time difference of arrival) and Doppler (frequency difference of arrival) measurements for each detected target are extracted. The measurement data are associated by target and a tracking filter estimates the state vector (position, velocity, and acceleration) for each target. This state data can then be presented to a tactical display or communicated to other systems via standard data-links.

In the current version of SS2, coarse 2-D tracking solutions are possible when the target is detected using a single illuminator. Good 2-D solutions are feasible whenever the target is detected on two or more geometrically...
• *Fourier domain imaging condition & migration aliasing*

• Fourier domain time windowing

• Gather convolution

• Forward-scattered angle gathers

• Valhall data

• 100% accurate \( \omega - k \) propagator

• Combined Linear/Hyperbolic radon transforms
FDIC & aliasing

\[ I(x, h)|_{\omega, z} = U(x + h) D^*(x - h) \]

\[ \hat{I}(k_x, k_h)|_{\omega, z} = \frac{1}{2} \hat{U} \left( \frac{k_x + k_h}{2} \right) \hat{D}^* \left( \frac{k_x - k_h}{2} \right) \]

derivation
FDIC & aliasing

Fourier domain

Space domain
FDIC & aliasing

Fourier domain

Space domain
FDIC & aliasing

Fourier domain

Space domain
FDIC & aliasing

shallow

deep
FDIC & aliasing

every 10th shot

all shots

brad@sep.stanford.edu
FDIC & aliasing

\[ \hat{I}(k_x, k_h) = \frac{1}{2} \hat{U} \left( \frac{k_x + k_h}{2} \right) \hat{D}^* \left( \frac{k_x - k_h}{2} \right) \]

<table>
<thead>
<tr>
<th>( k_x )</th>
<th>( k_h )</th>
<th>(-1)</th>
<th>( 0)</th>
<th>( 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-1)</td>
<td>( \hat{U} \left( \frac{-1}{2} \right) \hat{D}^*(0) )</td>
<td>( \hat{U} \left( \frac{-1}{2} \right) \hat{D}^* \left( \frac{-1}{2} \right) )</td>
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<td>( 2)</td>
<td>( \hat{U} \left( \frac{1}{2} \right) \hat{D}^* \left( \frac{3}{2} \right) )</td>
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2004

- Fourier domain imaging condition & migration aliasing
- Fourier domain time windowing
- Gather convolution
- Forward-scattered angle gathers
- Valhall data
Fourier domain time windowing
Fourier domain time windowing
2004

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Gather correlation

<table>
<thead>
<tr>
<th>Shot-profile</th>
<th>Survey sinking</th>
<th>Passive imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{z=0}(x_r, x_s, \omega)$</td>
<td>$D_{z=0}(x_r, x_s, \omega)$</td>
<td>$R_{z=0}(x_r, x_s, \omega)$</td>
</tr>
<tr>
<td>$SSR^{-1}$</td>
<td>$SSR^{+1}$</td>
<td>DSR</td>
</tr>
<tr>
<td>$U_{z=1}(x_r, x_s, \omega)$</td>
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<td>$R_{z=1}(x_r, x_s, \omega)$</td>
</tr>
<tr>
<td>$T_{z=0}(x_r, \omega)$</td>
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<td>$SSR^{-1}$</td>
</tr>
</tbody>
</table>

brad@sep.stanford.edu
Gather correlation

Shot-profile = Source-receiver migration

\[ R_{z+1} = DSR R_z = DSR U_z D_z^* = \]
\[ = SSR U_z SSR D_z^* = \]
\[ = SSR U_z (SSR^{-1} D_z)^* = U_{z+1} D_{z+1}^* . \]
Gather convolution

Image space SRME:

\[
M_{z+1} = \text{DSR } M_z = \text{DSR } U_z U_z^* = (2)
\]
\[
= \text{SSR } U_z \text{ SSR } U_z^* =
\]
\[
= \text{SSR } U_z (\text{SSR}^{-1} U_z)^* = U_{z+1} U_{z+1}^*.
\]
Migration
Image-space multiple model
Migration, subtraction
Subtraction, migration
2004

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Forward-scattered angle gathers
Forward-scattered angle gathers

\[ x \left( p_r + p_s \right) + z \left( q_r + q_s \right) - h_x \left( p_r - p_s \right) - h_z \left( q_r - q_s \right) = 0, \]

\[ \frac{\partial z}{\partial h_x} = -\tan \gamma \quad \text{and} \quad \frac{\partial z}{\partial x} = -\tan \alpha. \]

\[ x \left( p_r - p_s \right) + z \left( q_r - q_s \right) - h_x \left( p_r + p_s \right) - h_z \left( q_r + q_s \right) = 0, \]

\[ \frac{\partial z}{\partial h_x} = -\cot \gamma_a \quad \text{and} \quad \frac{\partial z}{\partial x} = -\cot \alpha_a. \]
2004

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Valhall
Valhall

Station

0 1 2 3 4 5 6

Brad@sep.stanford.edu

28
• Valhall passive data

• Plan-wave decomposition & spectral analysis

• migrate P,Z, & S components
  ★ Back-scattered
  ★ Forward-scattered

• P-Z summation as $U \ D$ separation vs. correlation

• Compare to “best-case” image

• Search for earth tremor
2005b

- Finish aliasing paper
- Finish image-space multiple modeling paper
- Direct migration of Long Beach VSP data
- Submit multi-offset GPR migration paper
Thanks

contents
• Fourier domain imaging condition & migration aliasing
• Fourier domain time windowing
• Gather convolution
• Forward-scattered angle gathers
• Valhall data
Derivation 1

\[ I(x, h) \big|_{\omega, z} = U(x_r - h) D(x_s + h) \quad (1) \]

Fourier transform \( D \) to \( \hat{D} \)

\[ \hat{I}(x, h) = U(x - h) \int \hat{D}(k_s) e^{i k_s(x+h)} dk_s \quad (2) \]

FT all the \( x \)'s

\[ \hat{I}(k_x, h) = \int U(x - h) \int \hat{D}(k_s) e^{i k_s(x+h)} dk_s e^{-i x k_x} dx \quad (3) \]
Derivation 2

Introduce (Sergey inspired) variable flip-flop/reorder

\[ \hat{I}(k_x, h) = \int \hat{D}(k_s) e^{ik_sh} \int U(x - h) e^{-ix(k_x - k_s)} dx dk_s \]

\[ \hat{I}(k_x, h) = \int \hat{D}(k_s) e^{ih(2k_s - k_x)} \int U(x - h) e^{-i(x-h)(k_x - k_s)} d(x - h)dk_s \] (4)

Note salient details: Inner integral is FT of \( U \),

\[ \hat{I}(k_x, h) = \int \hat{U}(k_x - k_s) \hat{D}(k_s) e^{ih(2k_s - k_x)} dk_s \] (5)
Derivation 3

knowing $k_h = 2k_s - k_x$,

$$\hat{I}(k_x, h) = \frac{1}{2} \int \hat{U}\left(\frac{k_x - k_h}{2}\right) \hat{D}\left(\frac{k_x + k_h}{2}\right) e^{-ihk_h} dk_h$$  \hspace{1cm} (6)

This we see is FT over offset, so the complete FT of the IC is

$$\hat{I}(k_x, k_h) = \frac{1}{2} \hat{U}\left(\frac{k_x - k_h}{2}\right) \hat{D}\left(\frac{k_x + k_h}{2}\right).$$  \hspace{1cm} (7)

return