Synthetic aperture acoustic imaging of canonical targets with a 2-15 kHz Linear FM chirp

Synthetic aperture image reconstruction applied to outdoor acoustic recordings is presented. Acoustic imaging is an alternate method having several military relevant advantages such as being immune to RF jamming, superior spatial resolution, capable of standoff and forward-looking scanning, and relatively low cost, weight and size when compared to 0.5 – 3 GHz ground penetrating radar technologies. Synthetic aperture acoustic imaging is similar to synthetic aperture radar but more akin to synthetic aperture sonar technologies owing to the...
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ABSTRACT

Synthetic aperture image reconstruction applied to outdoor acoustic recordings is presented. Acoustic imaging is an alternate method having several military relevant advantages such as being immune to RF jamming, superior spatial resolution, capable of standoff side and forward-looking scanning, and relatively low cost, weight and size when compared to as compared to 0.5 – 3 GHz ground penetrating radar technologies. Synthetic aperture acoustic imaging is similar to synthetic aperture radar but more akin to synthetic aperture sonar technologies owing to the nature of longitudinal or compressive wave propagation in the surrounding acoustic medium. The system’s transceiver is a quasi mono-static microphone and audio speaker pair mounted on a 5-meter rail. Received data sampling rate is 80 kHz with a 2-15 kHz Linear Frequency Modulated (LFM) chirp with a pulse repetition frequency (PRF) of 10 Hz and an inter-pulse period (IPP) of 50 milliseconds. Targets are positioned within the acoustic scene at slant range of two to ten meters on grass, dirt or gravel surfaces and with and without intervening metallic chain link fencing. Acoustic image reconstruction results in means for literal interpretation and quantifiable analyses. A rudimentary technique characterizes acoustic scatter at the ground surfaces. Targets within the acoustic scene are first digitally spotlighted and further processed providing frequency and aspect angle dependent signature information.

Conference Name: SPIE Defense Sensing
Conference Date: April 25, 2011
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Synthetic Aperture Acoustic Imaging

25 April 2011

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The backscatter of pulses directed at a stationary target, launched and received from a moving transceiver, can be processed to form images.

The resolution of these images is set by the travel range of the moving transceiver rather than by the physical size of the components.

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Acoustic Imaging

Imaging can be done with light, RF, sound or, potentially, other forms of radiation.

Acoustic radiation is worth considering because:
- Objects that are opaque to light or RF might be translucent or transparent to sound.
- Safety issues are limited and relatively easy to mitigate.
- System costs are low.
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SAA images leads to 2D acoustic *signature* of an individual target which is determined by structural attributes including stiffness, density, shape and orientation.
Wavelength and Resolution

Acoustic imaging can produce different information than other approaches because structures interact differently with sound than other forms of radiation.

SAA wavelengths are smaller than SAR wavelengths: enhanced resolution.
2010 Progress

Refined existing side-looking Synthetic Aperture Acoustic (SAA) imaging system

Analyzed more realistic data with relevant targets and clutter
  Outdoor and indoor measurements at CUA

Completed a field data collection
  Outdoor measurements at an Army test site
Measurement System

Side-looking rail mounted SAA transceiver

Outdoor test sites include a variety of surfaces, background structures and environmental conditions.
Specifications & Parameters

System Specifications

Travel range: 5 m
Chirp band: 2-15kHz
Slant range: 2-15m

Study Specific Parameters

Repetition rate: 10Hz
Chirp duration: 10 & 40ms
SPL at target: <105dB
Pulse diversification 0%
Depression angle: 12.5°-30°
Field Measurements
Field Measurements

Speaker/microphone combination transceiver
Field Measurements

Speaker/microphone combination transceiver

Carriage travels along 5 m rail
Field Measurements

Speaker/microphone combination transceiver
Carriage travels along 5 m rail

Targets were placed on dirt, gravel, and grass surfaces at 2-9 m range.
Targets and Surfaces

a. Dirt and grass without any targets

b. Propped concave capped cylinder (CCC)
   • on dirt and grass
   • behind a metallic chain link fence

c. Spherical targets (bowling ball and softball)
   • on dirt and grass
   • behind a metallic chain link fence

d. Material study
   • open and closed cell foam
   • ceiling panels
   • slate

e. Large artillery shell

f. Human
Field Measurements

• **Test Environment Conditions:**
  • no recent rain
  • temperature was below freezing point
  • strong winds were present
  • background noise from nearby sites

Adaptive frequency domain filtering was used to suppress the acoustic noise signature of the wind and background noise.
Environmental Noise

Before adaptive filtering

Matched-Filtered Measured Data

Radial Range, m

Synthetic Aperture, m

0 0.5 1 1.5 2

-2 -1.5 -1 -0.5 0

12 14 16

6 8 10

4 2
Environmental Noise

After adaptive filtering

SAA Data After Frequency Filtering
Cumulative spectrum indicates usable bandwidth between 2 and 16 kHz
Concave Capped Cylinder (CCC)

Unobscured target

Obscured by chain-link fence

Wavefront Reconstruction

Wavefront Reconstruction
Concave Capped Cylinder (CCC)

Unobscured target

Obscured by chain-link fence
Concave Capped Cylinder (CCC)

Unobscured target

Obscured by chain-link fence

Chain-link fence has minimal effect on signature
Concave Capped Cylinder (CCC)

Target on dirt

Target on grass
Concave Capped Cylinder (CCC)

Target on dirt

Target on grass

Different surfaces exhibit similar acoustic signature...
Concave Capped Cylinder (CCC)

Target on dirt  
Target on grass

... however, grass introduces high frequency attenuation
Target Elevation

Wavefront Reconstruction

Azimuth, m

Slant Range, m

Target Elevation

Wavefront Reconstruction

Azimuth, m

Slant Range, m

Target Elevation

Wavefront Reconstruction

Azimuth, m

Slant Range, m

Target Elevation

Wavefront Reconstruction

Azimuth, m

Slant Range, m
Elevation Comparison

bowling ball on surface

bowling ball elevated 1 inch

bowling ball elevated 2 inches
Elevation Comparison

- Bowling ball on surface
- Bowling ball elevated 1 inch
- Bowling ball elevated 2 inches

Signature is sensitive to target elevation due to multi-path effects
Target Materials

Reconstruction of foam panels on dirt
Target Materials

Open-cell foam panel

Closed-cell Styrofoam panel

Acoustic Magnitude Signature

Acoustic Magnitude Signature
Target Materials

Open-cell foam panel

Closed-cell Styrofoam panel

Amplitude is dramatically affected by material
Human Target

Reconstruction of a human supine on dirt (SAA_143038,).
**Conclusions**

**Robust Data Acquisition:** data was successfully collected outdoors under uncontrolled ambient conditions

- Data is robust to environmental acoustic noise (wind, vehicular traffic, gunfire and explosions)
- Acoustic measurements are not influenced by EMI

**Geometric characterization:** targets and target configurations have distinct and repeatable signatures

- Signatures are not sensitive to ground surface type but are sensitive to target elevation
- Signatures can be obtained despite the presence of obscurants (e.g., chain-link fence)

**Material characterization:** comparison of samples of different materials (with identical geometry) show differences in signature and amplitude

- Distinguish different bulk properties (stiffness, density) and surface characteristics (roughness, porosity, surface impedance)
Backup Slides
Surface Environment: Dirt

Reconstruction of lightly textured soil on a dirt lane (SAA_100616).
Surface Environment: Dirt

2D signature of lightly textured soil on a dirt lane (SAA_100616).
Surface Environment: Dirt

Dirt area 1D broadside signature lightly textured soil on a dirt lane (SAA_100616).
Surface Environment: Grass

Reconstruction of grass area (SAA_113821).
Grass area 2D signature (SAA_113821).
Surface Environment: Grass

Grass area 1D broadside signature (SAA_113821).