Robust Wideband Waveforms for Synthetic Aperture Radar (SAR) and Ground Moving Target Indication (GMTI) Applications

DARPA SBIR Topic: SB082-020, Phase II
Army Contract W31P4Q-11-C-0043

Program Summary
September 2, 2015

Jamie Bergin
John Pierro

Work funded by the Defense Advanced Research Projects Agency under Army Contract W31P4Q-11-C-0043

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8130 Boone Blvd. Suite 500
Vienna, Virginia 22182
(703)448-1116 FAX: (703)356-3103
www.islinc.com

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Outline

• Background
• Data Collection Summary
• Processing Results
• Next Phase
GMTI and Small UAVs

Air Force JSTARS

- >5 meter antenna
- 3 receive channels

Telephonics ZPY-4

~20 in. antenna
2 receive channels

Fire Scout UAV (unmanned Bell 407)

- Cost, Size, weight, and power (SWAP) constraints severely limit the antenna size and numbers of instrumented channels
- Slower UAV platform speeds can potentially help but can lead to sub-optimal endurance
Solution: Multiple Input, Multiple Output (MIMO) Radar

- A unique mode that exploits multi-waveform and spatial diversity to enhance spatial and temporal resolution

- Particularly well-suited for small UAV radars with limited aperture

- Made possible by recent advances in digital RF front ends in particular digital waveform generators

filter $h_n$ is matched to transmit signal $s_n(t)$ and has low correlation with all other signals
MIMO Radar Properties

- MIMO radar provides a virtual increase in the antenna aperture
- The virtual array positions are the convolution of the transmit and receiver array element position

\[
\begin{align*}
\text{real receive array} & \quad \{1 \quad 1\} \\
\text{real transmit array} & \quad \{1 \quad 1\} \\
\text{MIMO virtual array} & \quad \{1 \quad 2 \quad 1\}
\end{align*}
\]

- Provides longer aperture and additional spatial channels needed for GMTI mode

Radar Performance Improvement

![Graphs showing performance comparison between conventional and MIMO systems for slow-moving and fast-moving targets.]

**Slow-Moving Targets**
- MIMO provides >2x improvement in target geolocation accuracy for slow-moving targets.

**Fast-Moving Targets**
- MIMO also provides better geolocation for fast-moving targets.

**Better geolocation accuracy, fewer false alarms, robustness to jamming**
ZPY-4 Based MIMO Demonstration Unit

New MIMO Architecture

- Tx waveform (½ power into each path)
- Full aperture beams
- "same" as Doppler Domain Multi-Access (DDMA)
- Fixed phase shifts (time delays)
- Switching pulse to pulse

Laboratory Hardware

- High power RF switches and phase shifters
- Fabricated by Microwave Applications Group (MAG)

Final integration and laboratory testing completed 7/14

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Data Collection Overview

- Good data collected 4/30/15 and 5/4/15
  - 8 radar passes (4 water, 4 land)
  - MIMO and baseline GMTI data
- Endo-clutter MTS target for most over-land passes
- Instrumented GPS vehicle (4 door sedan) for half the overland passes
- Many targets of opportunity
Example Clutter Maps

MIMO: Water

Baseline GMTI: Water

MIMO: Land

Baseline GMTI: Land

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MIMO Processing Flow

IQ samples

Form MIMO channels (forward and aft beams)

Mocomp apply calibration

Range/Doppler process all Rx and Tx Channels

MIMO-STAP
Multi-bin post Doppler Element space
(5 Dop bins, 2 Rx, 2 Tx channels)

CACFAR

Bearing estimation (MLE)
MIMO Tx Beam Patterns

- Patterns estimated from MIMO over-water clutter data
- NOTE: Simple motion compensation used to convert Doppler axis to azimuth angle
Tx Calibration

• 2 Tx channels were successfully combined (beamformed) to produce a pattern with sidelobes and beamwidth similar to the GMTI mode.
Tx Calibration (cont.)

- Two Tx channels combined to form a narrow, low sidelobe beam in the antenna boresight direction.
- Tx pattern formed in the signal processor using the two available Tx channels.
- Beamwidth and sidelobes similar to GMTI transmit pattern.
Targets of Opportunity

- Many targets of opportunity detected

- Conventional beamforming
- CFAR normalization
- Largest targets have SNR order of 30 dB
Bearing estimates of targets of opportunity correlate well with the road.

We used the road data to compute and error between the estimated bearing and true target bearing.
Exo-Clutter Geolocation Estimates

- Targets with SNR > 30 dB
- |Doppler| between 300 Hz and 1000 Hz
- Single pass
Exo-Clutter Bearing Errors

- Single pass
• MTS Doppler: 97 Hz (3 kts)
• Radar data centered at MTS physical location
• MTS observed in STAP output
• Note: Doppler axis is flipped in radar data
**Endo-Clutter Bearing Errors**

- **MIMO** provides Greater than 2x improvement in bearing accuracy at higher SNRs