Fast-Time Clutter Suppression in mm-Wave Low-IF FMCW Radar for Fast-Moving Objects

Christopher Allen¹, Levi Goodman¹, Shannon D. Blunt¹, and David Wikner²

¹Radar Systems & Remote Sensing Lab (RSL), University of Kansas
²Sensors and Electron Devices Directorate, US Army Research Laboratory, Adelphi, MD

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Motivation

• Explore FMCW radar’s capability to simultaneously map static obstacles and fast-moving objects
  – fast mover’s observable time is too short for convention range-Doppler mapping

• W-band implementation to support mobile applications
  – high Doppler sensitivity

• Heterodyne (low IF) mode to distinguish positive from negative frequencies
  – Symmetric triangular frequency-vs-time FMCW waveform used

• Clutter suppression separates fast-mover’s echoes from static clutter
  – suppression performed in fast-time

• Experimentally demonstrated by firing “re-balls” (reusable paintballs)
System Description

- Dual DDS waveform generation
System Description

• Dual DDS waveform generation
  – synchronously clocked and triggered
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  - 500-μs upchirp and downchirp
System Description

- Dual DDS waveform generation
  - synchronously clocked and triggered
  - 500-μs upchirp and downchirp
  - offset Tx and Reference frequencies produce 3 MHz $f_0$ heterodyne IF
System Description

- Virginia Diodes W-band modules
  - ×6 freq mult
System Description

• Virginia Diodes W-band modules
  – ×6 freq mult
  – 108 GHz center frequency
System Description

• Virginia Diodes W-band modules
  – ×6 freq mult
  – 108 GHz center frequency
  – 600 MHz chirp bandwidth, B
System Description

• Spectra expected for upchirp Tx
System Description

- Spectra expected for upchirp Tx
  - static clutter
System Description

- Spectra expected for upchirp Tx
  - static clutter
  - fast-moving object (moving away from radar)
System Description

• Spectra expected for upchirp Tx
  – static clutter
  – fast-moving object (moving away from radar)

Note the spectral separation
System Description

- Spectra expected for downchirp Tx
System Description

• Spectra expected for downchirp Tx
  – static clutter (mirrored about $f_o$)
System Description

• Spectra expected for downchirp Tx
  – static clutter
  – fast-moving object (moving away from radar) assumes \( f_D \gg f_R \)
System Description

• Spectra expected for downchirp Tx
  – static clutter
  – fast-moving object (moving away from radar)

Note the lack of spectral separation
Test Setup and Measurement Results

- Tested in an unoccupied auditorium (clutter-rich environment)
- Paintball serves as fast-moving object ($v \approx 90 \text{ m/s}$)
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- Paintball serves as fast-moving object ($v \approx 90$ m/s)
- Paintball (actually a solid rubber 0.68" reball) fired away from the radar
- Fabric sheet safely absorbs paintball’s energy

Before impact  After impact
Test Setup and Measurement Results

- Tested in an unoccupied auditorium (clutter-rich environment)
- Paintball serves as fast-moving object ($v \approx 90$ m/s)
- Paintball (actually a solid rubber 0.68” reball) fired away from the radar
- Fabric sheet safely absorbs paintball’s energy
- Oscilloscope captures radar output (triggered by reball launch)
Test Setup and Measurement Results

Measured echograms

- Shot fired away from the radar (SFA)
- Spectral separation in upchirp data
Test Setup and Measurement Results

Measured echograms

- Shot fired away from the radar (SFA)
- Spectral separation in upchirp data
- Spectral overlap in downchirp data
Test Setup and Measurement Results

Measured echograms

- Shot fired away from the radar (SFA)
- Spectral separation in upchirp data
- Spectral overlap in downchirp data

- Need data from both upchirp and downchirp to unambiguously estimate of reball’s range and Doppler

- Hence need for clutter suppression
Test Setup and Measurement Results

Measured echograms

- Shot fired toward the radar (SFT)
- Spectral overlap in upchirp data
Test Setup and Measurement Results

Measured echograms

- Shot fired toward the radar (SFT)
- Spectral overlap in upchirp data
- Spectral separation in downchirp data
Test Setup and Measurement Results

Measured echograms

- Shot fired toward the radar (SFT)
- Spectral overlap in upchirp data
- Spectral separation in downchirp data

- Note that about 65 ms into the measurement there is an abrupt change in the spectrogram.

- This corresponds to the instant the reball impacts the sheet.
Clutter Suppression for Fast-Moving Objects

“fold-and-subtract” clutter suppression

- Clutter’s amplitude response from the *spectral separation* case is combined with the clutter’s phase response from the *spectral overlap* case to obtain a complete clutter spectral estimate, which is used to subtract the overlapped clutter.

- Performed independently for each fast-time data record composed of upchirp and downchirp spectral data.
Clutter Suppression for Fast-Moving Objects

Clutter suppression applied to measured “shot fired away (SFA)” data

> 25 dB clutter suppression
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> 25 dB clutter suppression
Conclusions

• mm-wave radar data were collected, demonstrating detectability of a 0.68” reball traveling at 90 m/s at ranges up to about 7 m.

• As expected, clutter obscures the fast-mover’s spectral signature during only half of the upchirp / downchirp cycles, providing clean data during the other half.

• Application of “fold-and-subtract” clutter cancellation resulted in > 25 dB suppression, improving range and Doppler estimation of the fast mover.