U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

FORWARD LOOKING SYNTHETIC APERTURE RADAR (FLSAR) CONCEPT FOR LANDING IN DEGRADED VISUAL ENVIRONMENTS (DVE)

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MOTIVATION

• Survivability of Future Vertical Lift Platforms is one of the Army’s modernization priorities
• Rotorcraft crashes caused by degraded visual environments (DVE) conditions account for a large number of casualties to US and allied forces
• We propose the development of a millimeter-wave (MMW) radar sensor to assist helicopter landing in DVE
• Current state-of-the-art in aircraft landing sensors:
  • Forward-looking infrared (FLIR) – cannot see through thick dust
  • Passive MMW scanning arrays – no range info, limited resolution
  • Active MMW radar based on 2-D scanning arrays – complex and costly
• The on-going DVE-M Army program integrates multiple sensors on one platform
• Landing in heavy brownout conditions is still a capability gap
• Current radar systems does not meet all SWAP-C and performance requirements
WHY FORWARD LOOKING SAR FOR DVE

- Our proposed solution: linear antenna array combined with forward-looking synthetic aperture radar (FLSAR) processing
- Different operation from both traditional side-looking SAR and 2-D scanning arrays
- Radar system operating in a MMW frequency band
- Simpler, less expensive, low SWAP, more robust solution for 3-D terrain mapping
- Emphasis shifted from hardware complexity (physical beamforming) to signal processing (computational beamforming)
- FLSAR requires accurate timing and position information to maintain coherent processing
• Low-frequency (0.5 – 2 GHz), ultra-wideband (UWB) radar
• 2 transmitters and 16 receivers in 2-m-wide antenna array
• Average power ~ 1 W, range up to 30 m
• System development between 2006 to present
• Applications: FOPEN, STTW, GPEN
FROM UWB TO MMW FLSAR

- ARL has been developing ground-based forward looking UWB, low frequency radar technology since 2006
- Multiple concealed target detection applications have been explored (FOPEN, GPEN, STTW)
- The DVE radar operates at longer ranges – higher frequencies required to obtain good cross-range and elevation resolution with the same aperture
- Moving the radar from ground- to airborne platform – new challenges in terms of SWAP, timing, vibrations, positioning information
- While the overall concept is similar, there are some distinct differences:
  - Vastly different operational frequencies
  - 2-D vs. 3-D imaging
DESIGN CONSIDERATIONS

• MMW radar technology offers the following advantages:
  • Good resolution in all dimensions
  • Better penetration (clouds, rain, dust) than IR and optical sensors
  • Low power, small size – especially antenna elements, but also circuitry
• Big technology advances in the commercial world, due to automotive radar and 5-G wireless communications
• Possible choices for frequency band: K (24 GHz), Ka (35 GHz), W (76 and 95 GHz)
• We aim for an image resolution < 0.5 m in all directions
• Estimated average transmitted power on the order of 1–10 W
• Operational range of a few hundred meters from the landing area
• The antenna array size constrained by platform considerations – this limits the achievable cross-range resolution
The forward looking linear array combined with forward motion subtends the same angle space as the 2-D phased array radar to achieve comparable resolution. Resolution in the third dimension comes from the signal bandwidth. 

Range Resolution = $f(BW)$
Cross/Vertical Resolution = $f(\Delta \phi, \Delta \theta, \lambda)$
SIMULATING A 3-D IMAGE OF LANDING ZONE WITH FLSAR

- Helicopter is on a 10° glide path for landing
- To generate resolution in elevation, the glide path is modified to include a 14-m-long level flight section – this allows an elevation angle change of 1°
- 1-m-wide antenna array – 0.4° physical aperture
- We modeled the radar sensing problem using Xpatch, in K-band (24 GHz) and Ka-band (35 GHz)
- Based on the model data, we simulated SAR images at 600 m, 300 m, and 150 m from landing
- Flat surface clear landing area (approximately 5 m by 8 m) surrounded by large rocks
MODELING SCENARIO – LARGE ROCKS AND TREE AS LANDING OBSTACLES

20 m by 20 m area

Top View

Clear Landing Area

Down-range

20 m by 20 m area

Clear Landing Area

Scene with rocks

Scene with rocks + tree

Pilot View ($\theta = 10^\circ$)
2-D SAR IMAGES – GROUND WITH ROCKS

<table>
<thead>
<tr>
<th>Range</th>
<th>K-band, BW = 200MHz</th>
<th>Ka-band, BW = 300MHz</th>
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</thead>
<tbody>
<tr>
<td>600 m</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
<td>300 m</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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<tr>
<td>150 m</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
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- These are 2-D ground-plane images obtained at 3 different ranges and 2 frequency bands
- Notice that resolution scales up with frequency
- Cross-range resolution improves at shorter ranges
2-D SAR IMAGES – SCENE WITH TREE

- Range = 600 m
- Range = 300 m
- Range = 150 m

**K-band, BW = 200MHz**

- Cross-range (m)
- Down-range (m)

**Ka-band, BW = 300MHz**

- Cross-range (m)
- Down-range (m)

- We cannot identify the tree in the 2-D ground-plane images
- Resolution in elevation (3-D imaging) is required for this purpose
Flying straight and level for a brief period, one can obtain a 3-D terrain map.
For SAFIRE UWB Radar \((f = 300 – 2000 \text{ MHz})\), we use Real Time Kinematic (RTK) satellite navigation (with IMU) to improve the precision of position data derived from GPS. Provides overall position accuracy of better than 2 cm. For forward looking DVE SAR, will need an order of magnitude increase in precision.

Potential Solutions:
- IMU for coarse correction followed by radar-signal-based correction
- Translational motion compensation
  - Envelope correlation
  - Global range alignment
- Platform vibration compensation and filtering algorithms
- Phase gradient autofocus

An all digital-signal-processing solution may be possible if relative positional accuracy is sufficient, rather than absolute accuracy.
DVE FLSAR MAJOR MILESTONES

Modeling and Simulation Engineering Trade Space Hardware Development FY18-FY20

Ground Demonstration Post-processing 4QFY20

Airborne Demonstration on JTARV Platform Real Time Operation 4QFY22

2018 2019 2020 2021 2022
• Developing a multi-year research program in FLSAR for DVE
  – Syncs up with CSA priority on Future Vertical Lift, Aircraft Survivability Equipment and Future Unmanned Aerial System S&T demo in 5 years
• The goal is to demonstrate a low-cost radar sensor for 3-D terrain mapping by the end of FY22
• The enabling technologies are mm-wave radar, linear antenna arrays and forward looking SAR
• Our development efforts will be focused on modeling, phenomenology, signal processing and hardware prototyping