U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

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

Traian Dogaru, Calvin Le and Anders Sullivan

U.S. Army Research Laboratory

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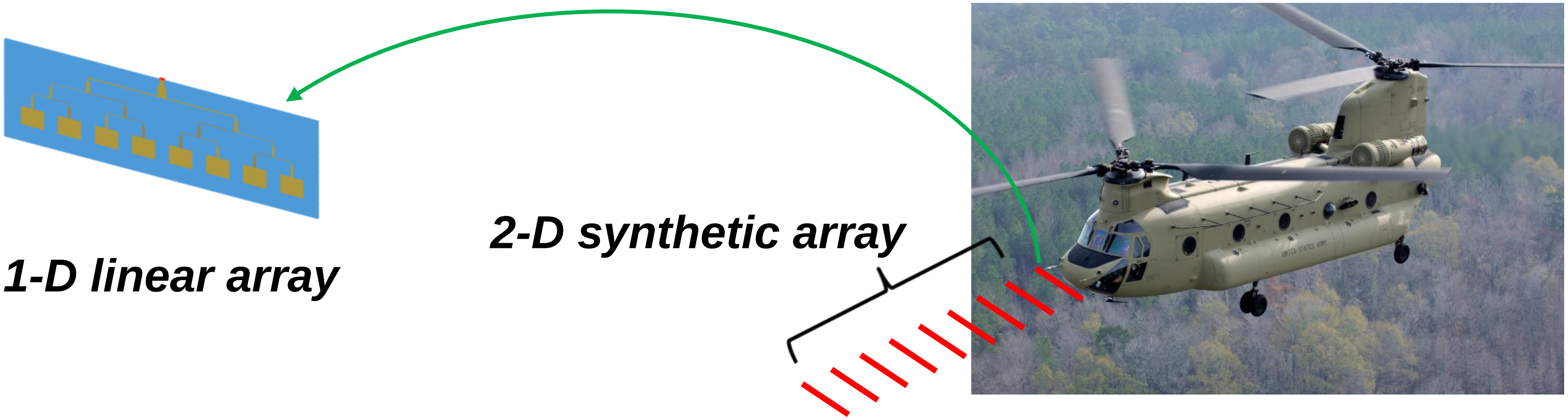
MOTIVATION

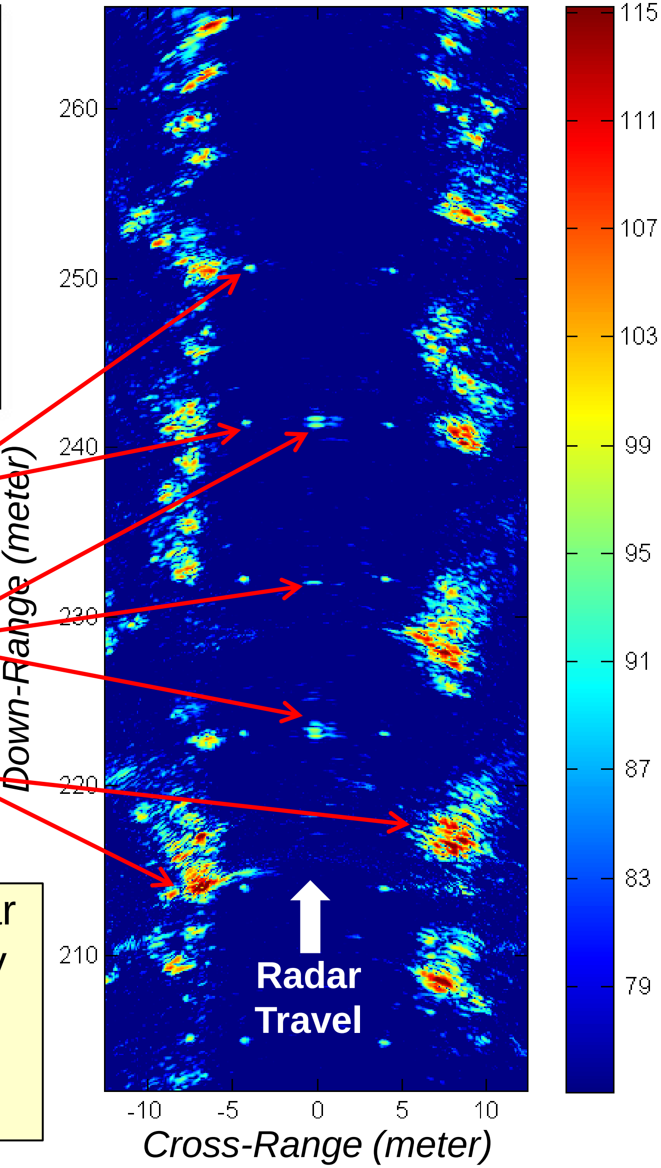
- Survivability of Future Vertical Lift Platforms is one of the Army’s modernization priorities
- Rotorcraft crashes caused by degraded visual environments (DVE) conditions account for a large number of casualties to US and allied forces
- We propose the development of a millimeter-wave (MMW) radar sensor 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



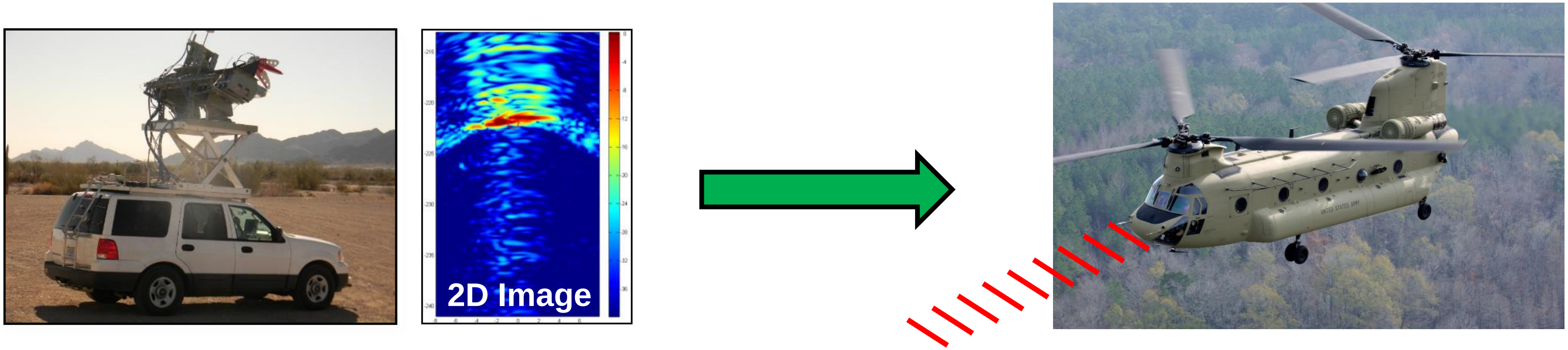
HISTORY OF FORWARD LOOKING RADAR AT ARL



- 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

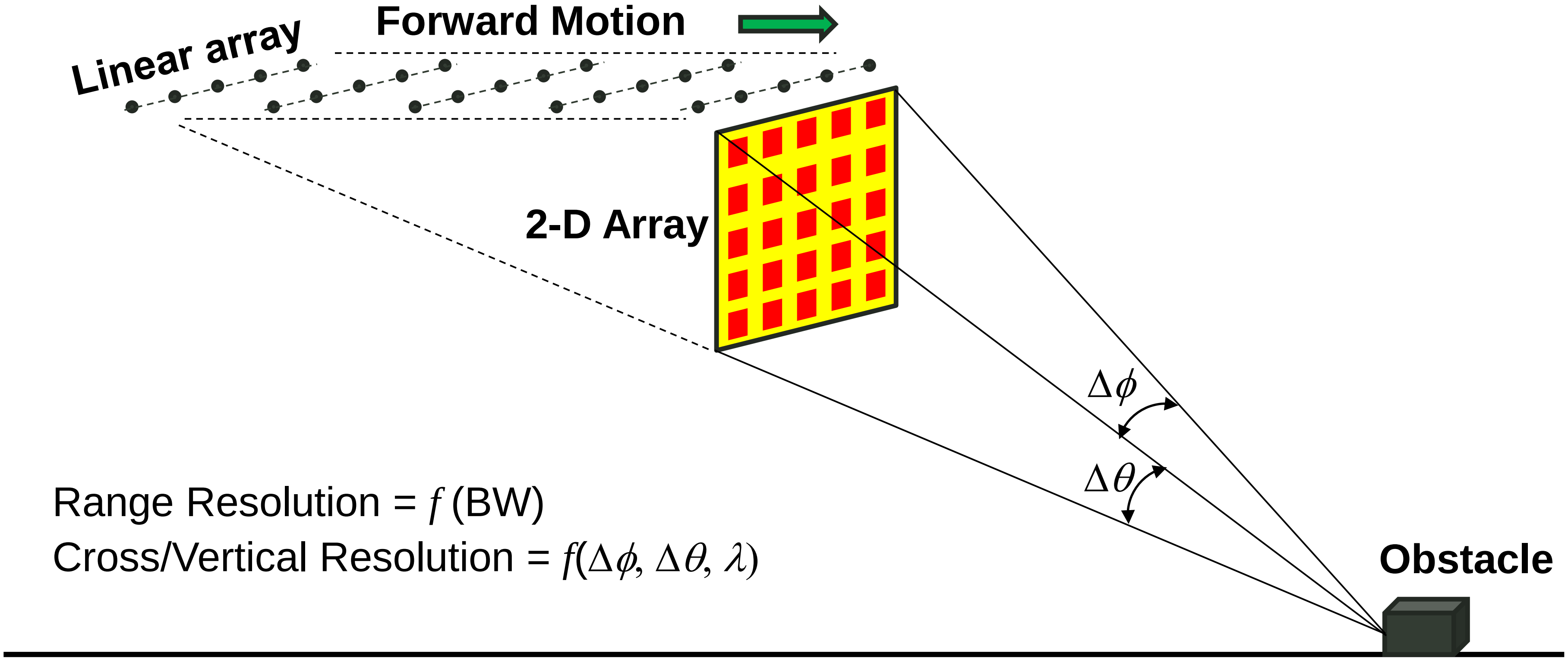
- ARL has been developing ground-based forward looking UWB, low frequency radar technology since 2006
- Multiple concealed target detection applications have been explored (FOPEN, GPEN, STTW)
- The DVE radar operates at longer ranges – higher frequencies required to obtain good cross-range and elevation 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

ANALOGY BETWEEN FLSAR AND 2-D PHASED ARRAY RADAR



Range Resolution = f (BW)

Cross/Vertical Resolution = $f(\Delta\phi, \Delta\theta, \lambda)$

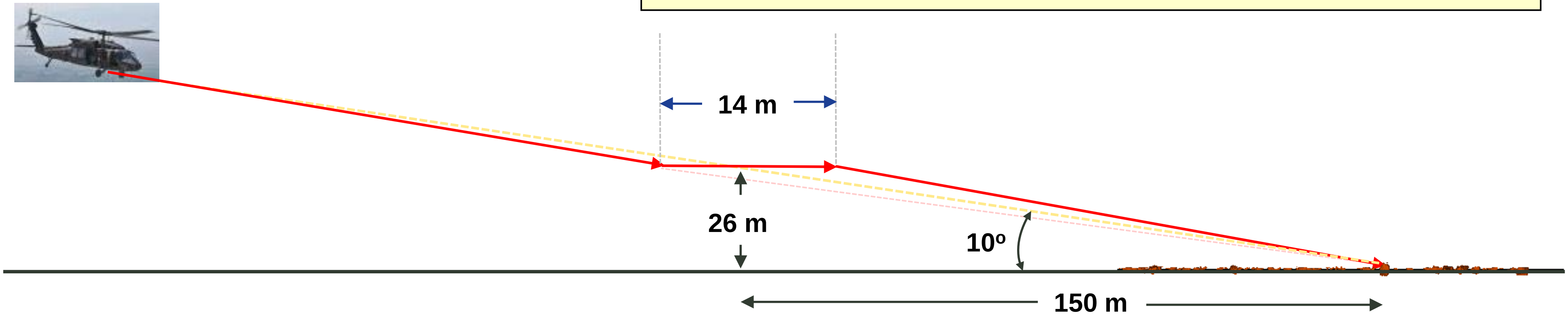
The forward looking linear array combined with forward motion subtends the same angle space as the 2-D phased array radar to achieve comparable resolution. Resolution in the third dimension comes from the signal bandwidth.

SIMULATING A 3-D IMAGE OF LANDING ZONE WITH FLSAR

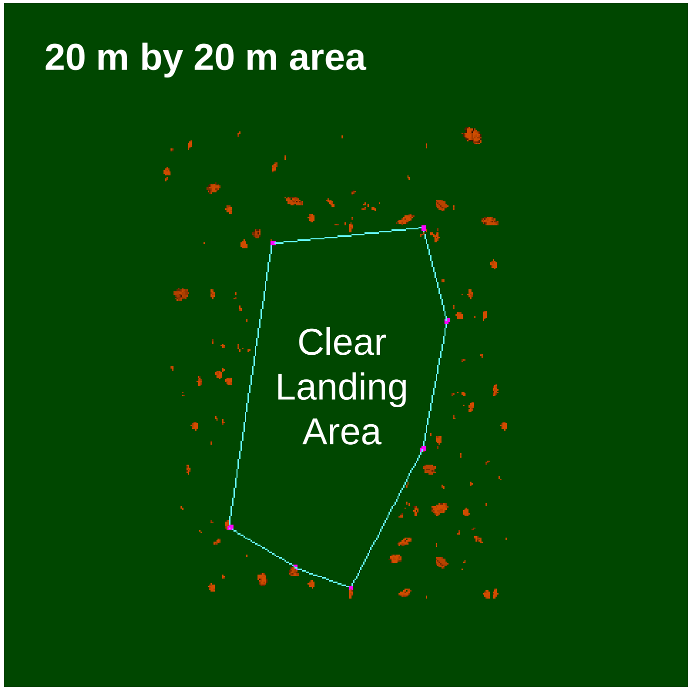
- Helicopter is on a 10º glide path for landing
- To generate resolution in elevation, the glide path is modified to include a 14-m-long level flight section – this allows an elevation angle change of 1º
- 1-m-wide antenna array – 0.4º physical aperture
- We modeled the radar sensing problem using Xpatch, 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

Constant 10º gliding path

Alternate gliding path

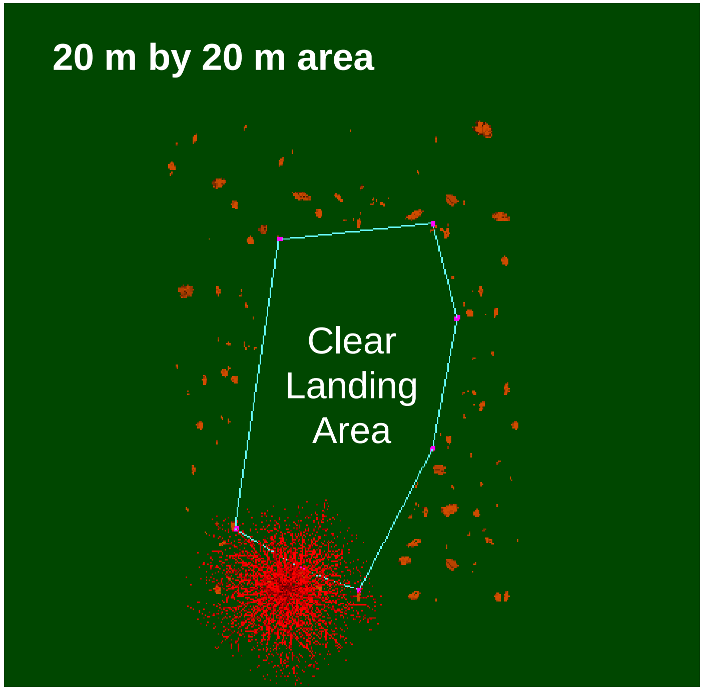


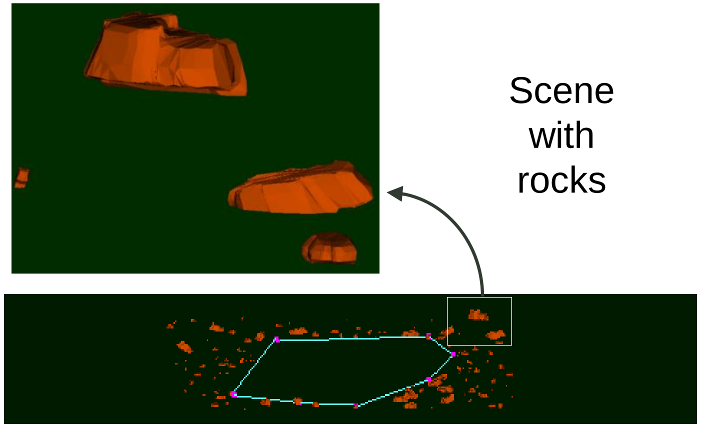
MODELING SCENARIO – LARGE ROCKS AND TREE AS LANDING OBSTACLES



Top View

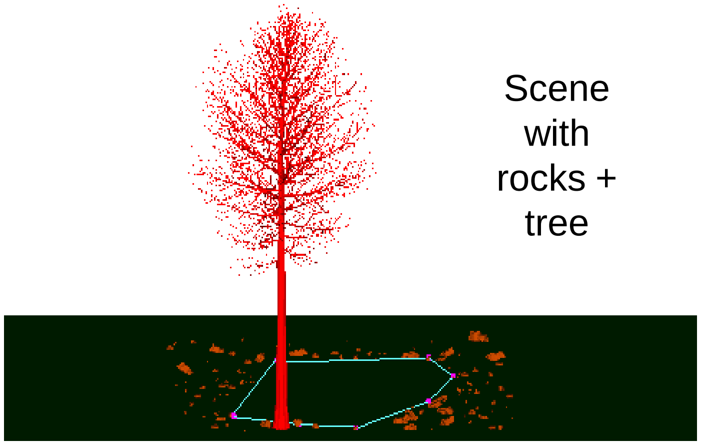
Down-range





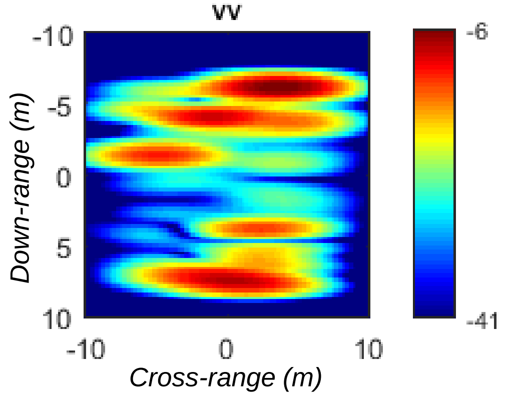
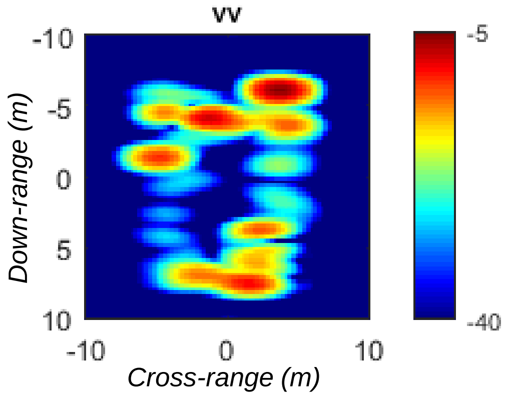
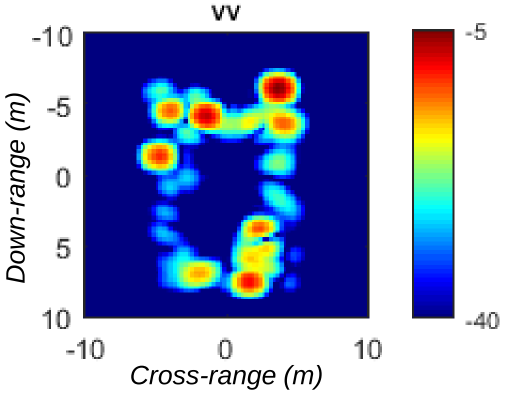
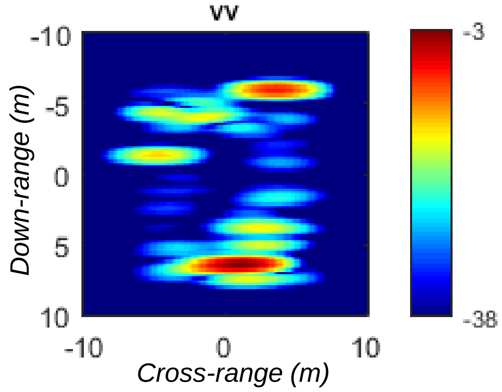
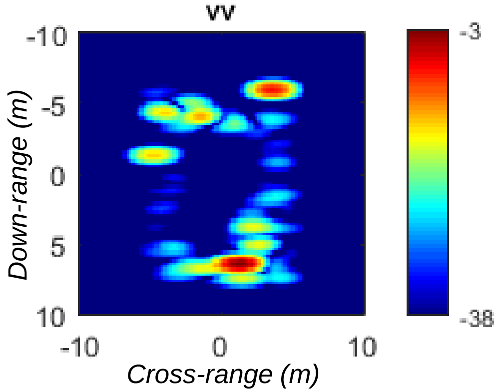
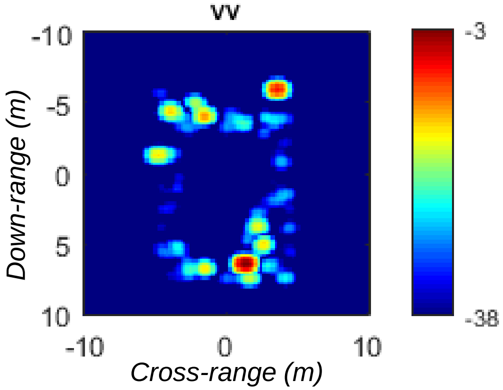
Scene with rocks

Pilot View
($\theta = 10^{\circ}$)



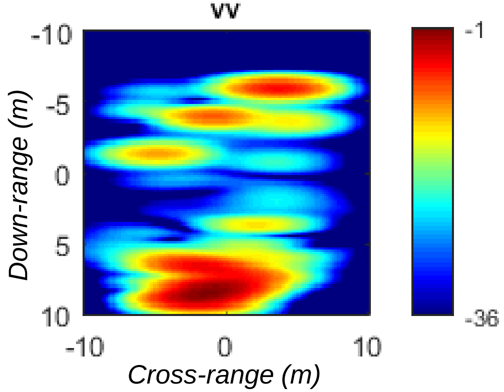
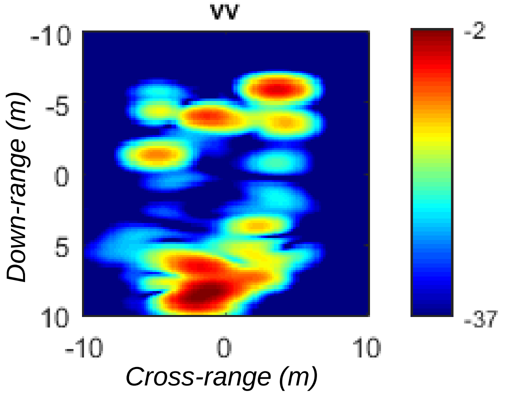
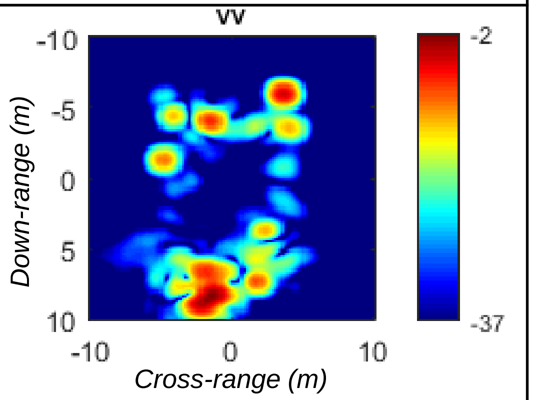
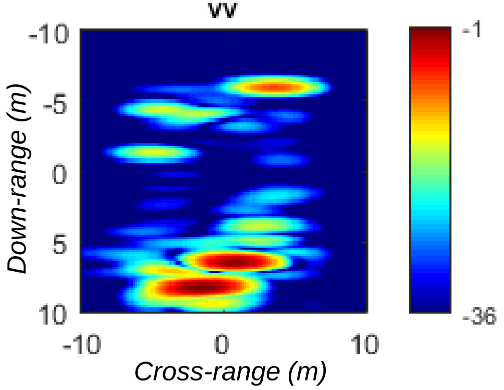
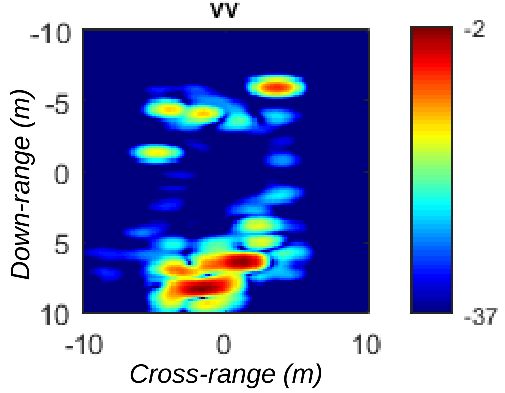
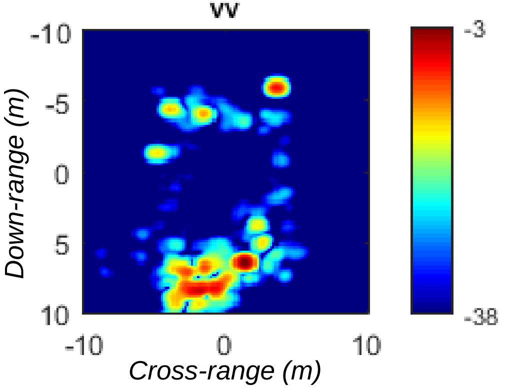
Scene with rocks + tree

2-D SAR IMAGES – GROUND WITH ROCKS

	Range = 600 m	Range = 300 m	Range = 150 m
K-band, BW = 200MHz			
Ka-band, BW = 300MHz			

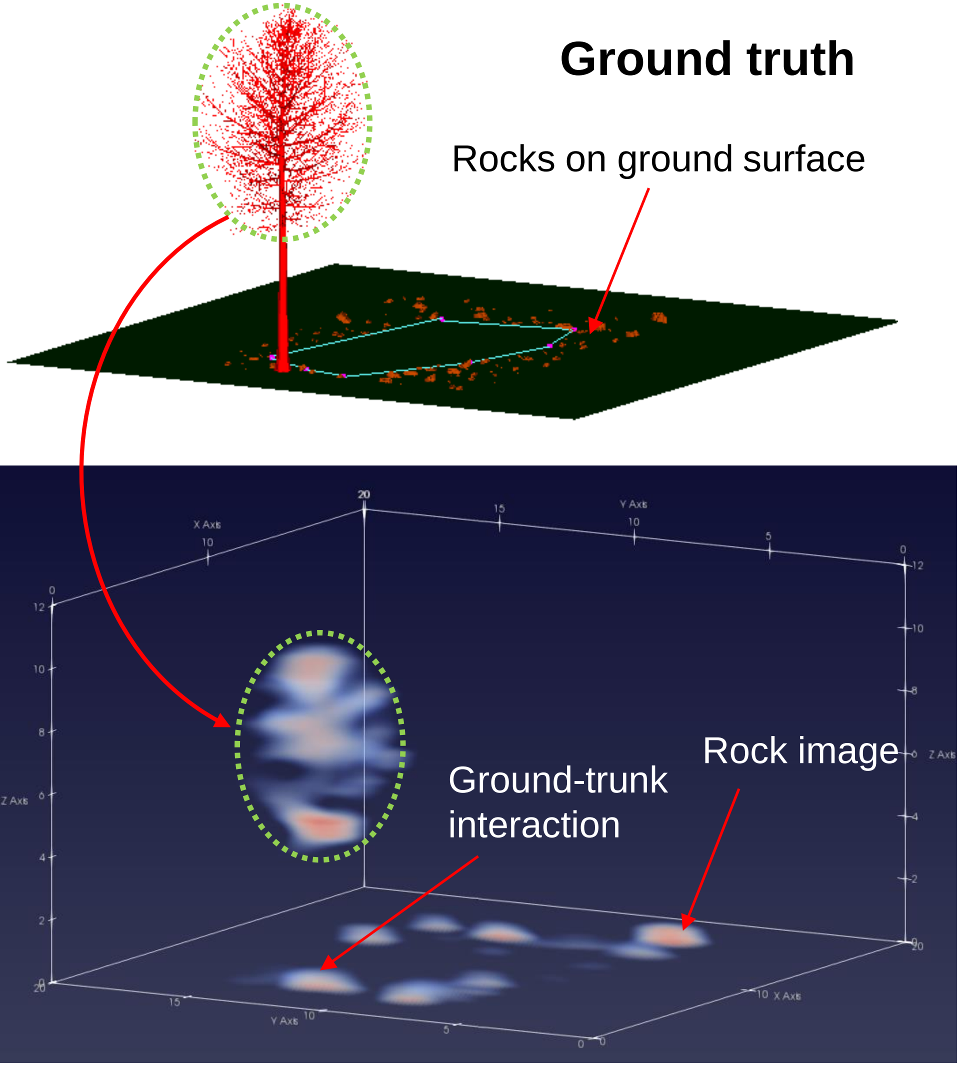
- These are 2-D ground-plane images obtained at 3 different ranges and 2 frequency bands
- Notice that resolution scales up with frequency
- Cross-range resolution improves at shorter ranges

2-D SAR IMAGES – SCENE WITH TREE

	Range = 600 m	Range = 300 m	Range = 150 m
K-band, BW = 200MHz			
Ka-band, BW = 300MHz			

- We cannot identify the tree in the 2-D ground-plane images
- Resolution in elevation (3-D imaging) is required for this purpose

3-D VISUALIZATION OF LANDING ZONE



Ground truth

Rocks on ground surface

Ground-trunk interaction

Rock image

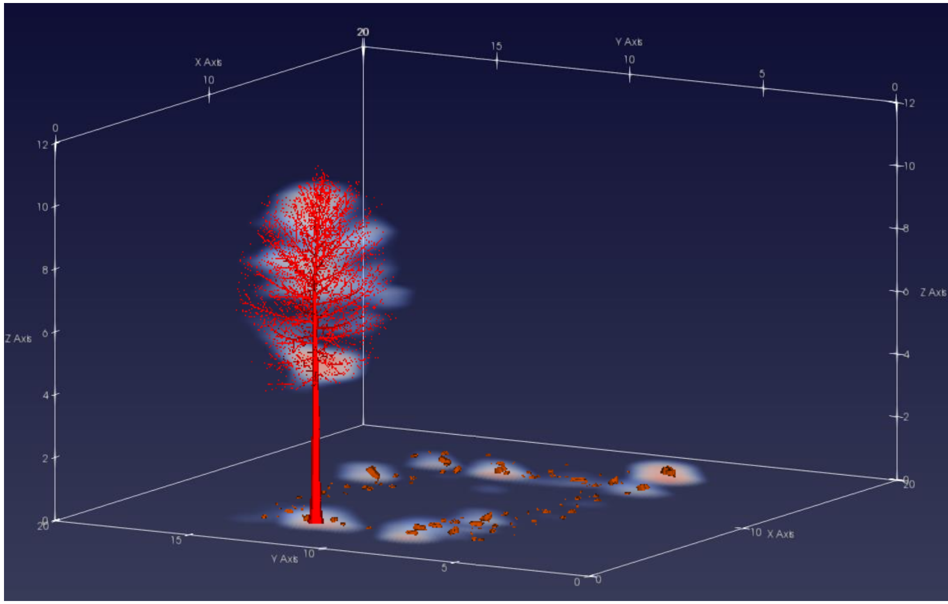
f_c = 24 GHz, BW = 200 MHz

$\theta = 10^\circ$, $\Delta\theta = 1^\circ$, $\Delta\phi = 0.4^\circ$

Range = 150 m

25 dB dynamic range

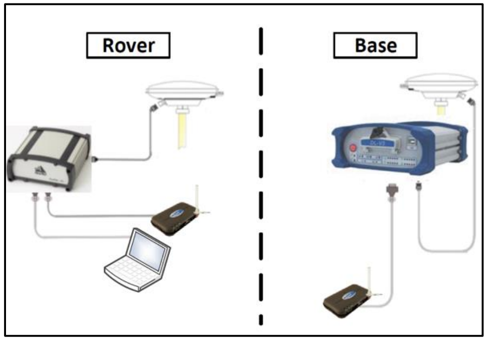
3-D radar image with ground truth overlay

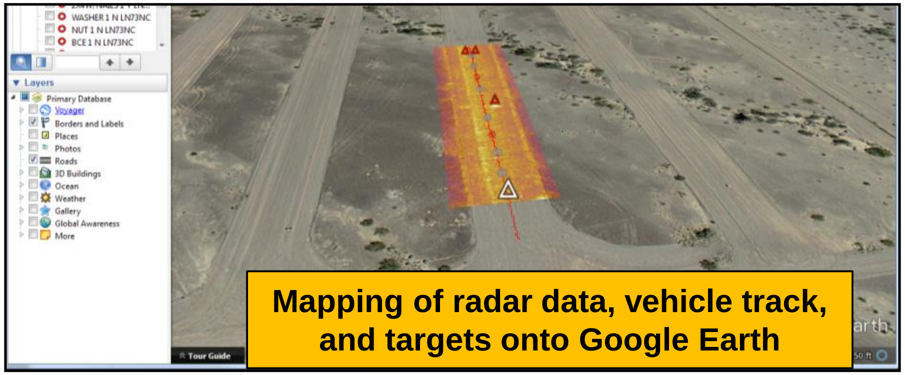


Flying straight and level for a brief period, one can obtain a 3-D terrain map

MOTION COMPENSATION OF SAR IMAGERY

SAFIRE Radar → GPS Hardware





Mapping of radar data, vehicle track, and targets onto Google Earth

For SAFIRE UWB Radar (f = 300 – 2000 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.

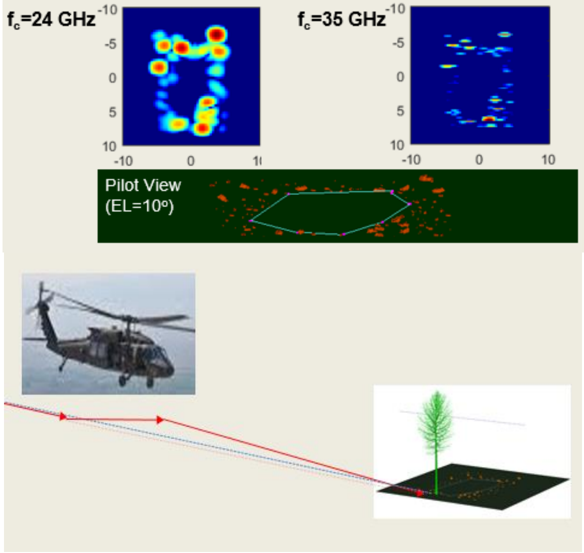
Forward Looking DVE SAR

Potential Solutions:

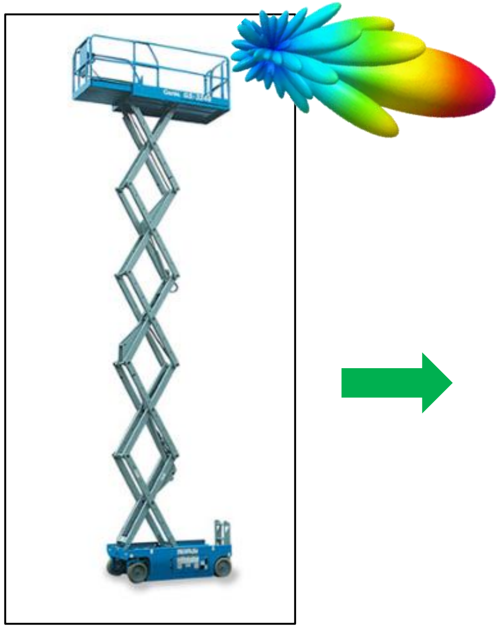
- IMU for coarse correction followed by radar-signal-based correction
- Translational motion compensation
  - Envelope correlation
  - Global range alignment
- Platform vibration compensation and filtering algorithms
- Phase gradient autofocus

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

SUMMARY

- 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