Radar Reprojection Mapping

Improves Obstacle Avoidance in Mobile Robots With an Unsteered Radar Sensor

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Master's Thesis

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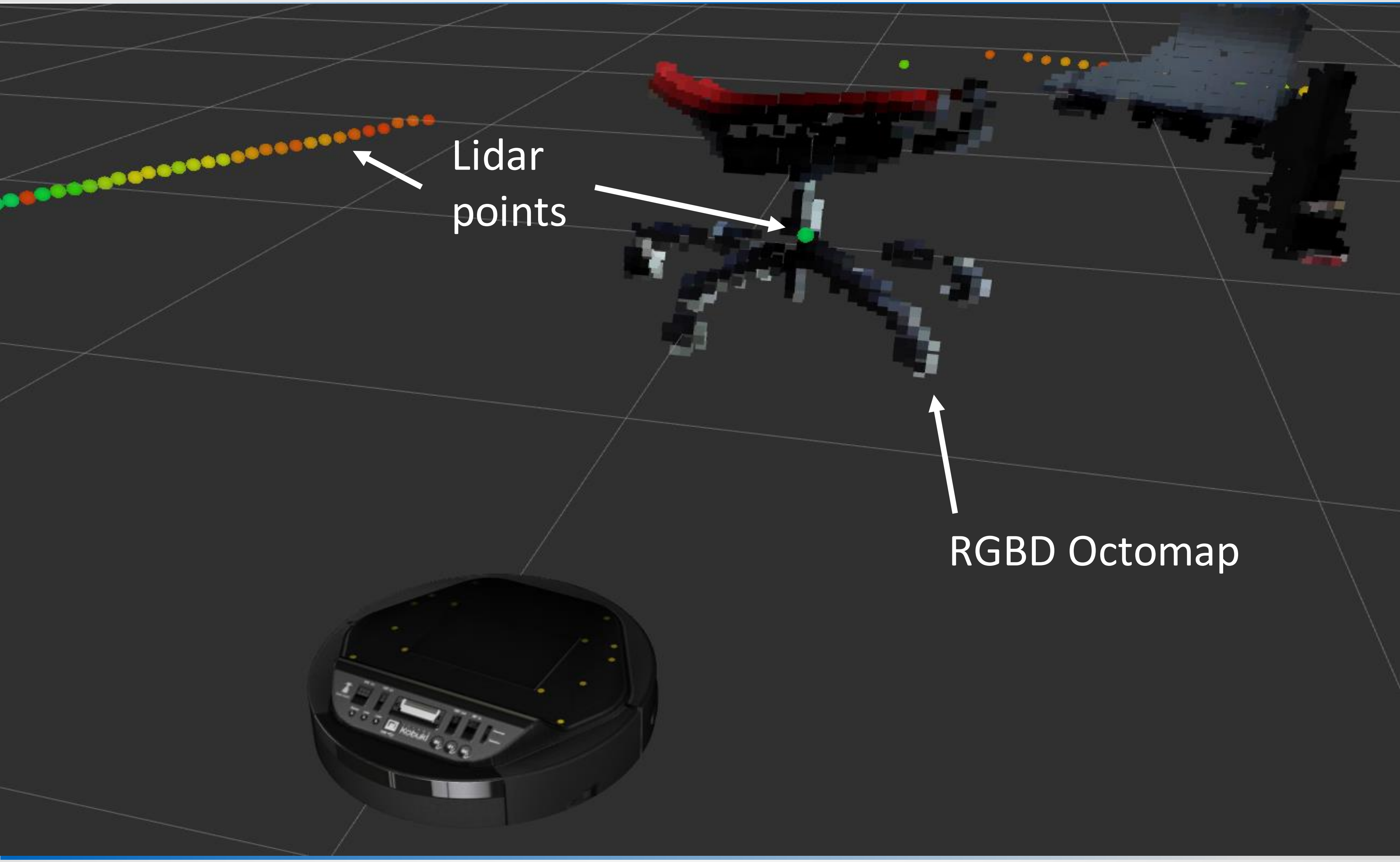
BSH Supervisor: Dr. Philip Roan

Palo Alto, October 28, 2017

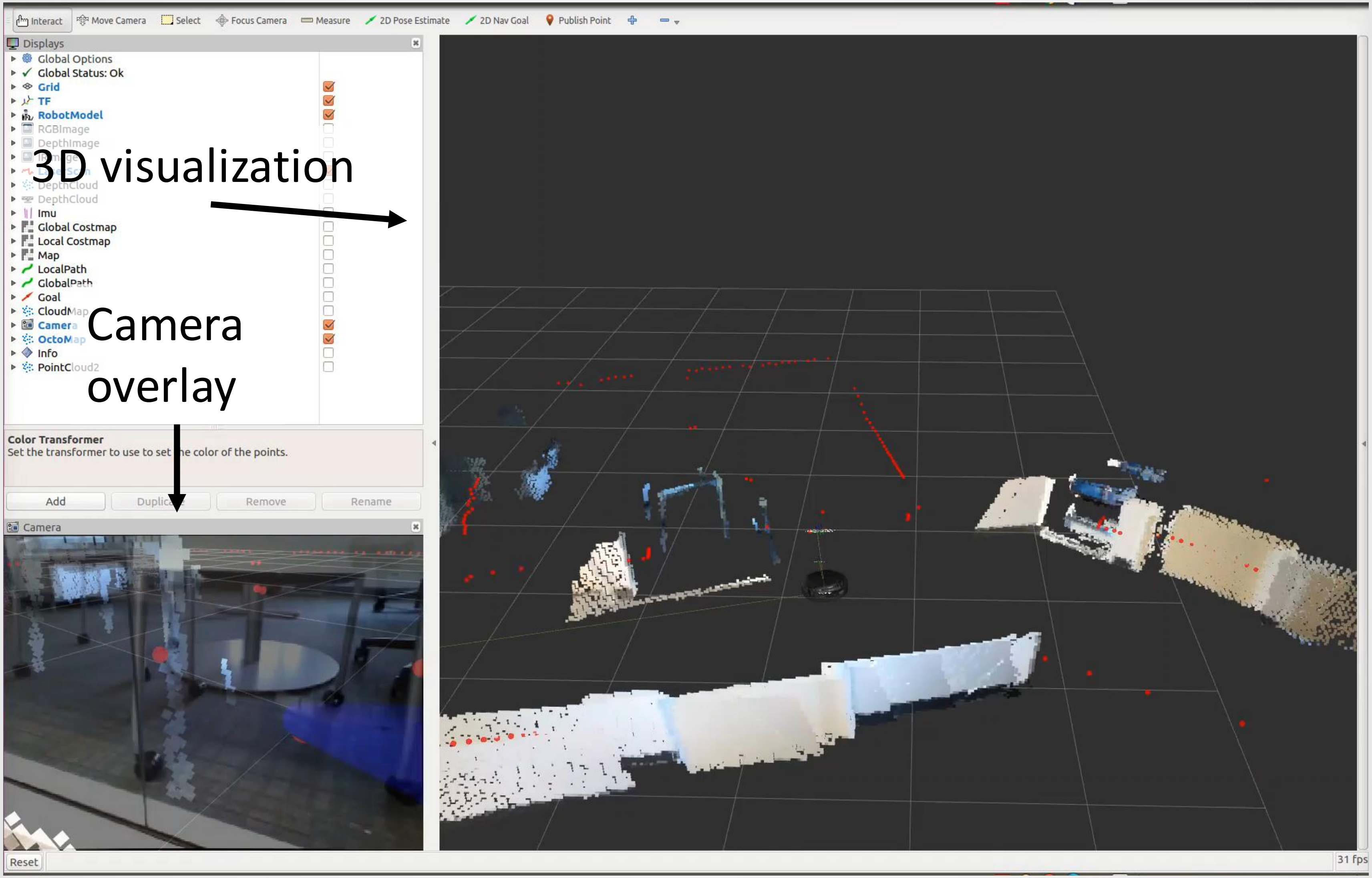
Obstacle detection is important

https://redd.it/5fs3wb

Invisible Chair legs



Transparent Windows



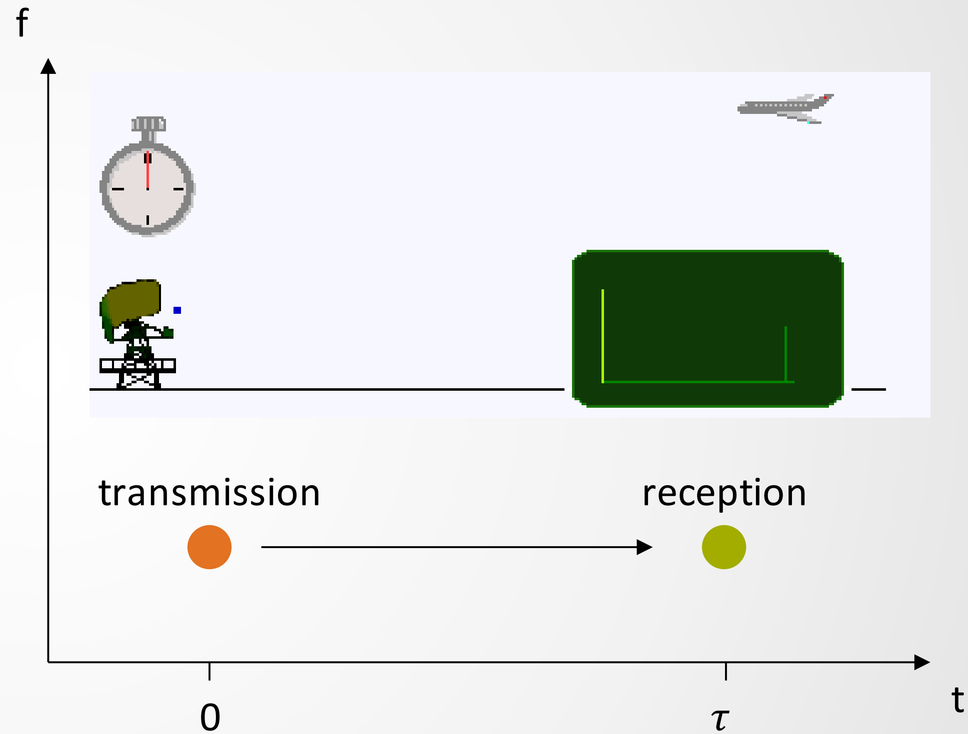
Radar

https://deepspace.jpl.nasa.gov/galleries/goldstone/

Pulsed Radar

1. Pulsed EM transmission
2. scatters at target and
3. is received back at t=τ

→ Target range $R = \frac{c\tau}{2}$



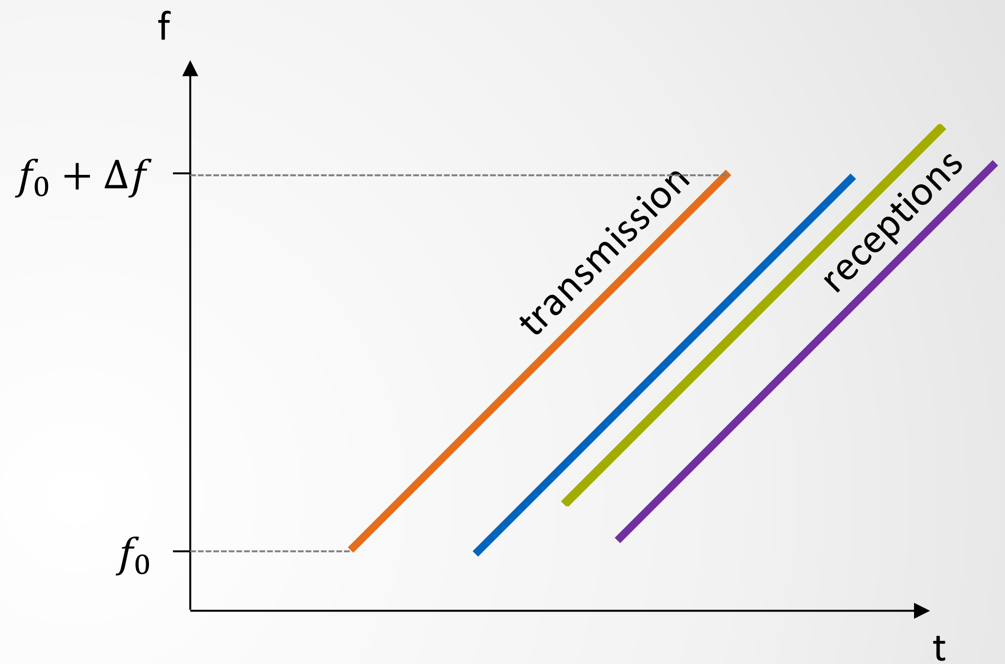
Averse K, https://de.wikipedia.org/wiki/Datei:Radaroperation.gif

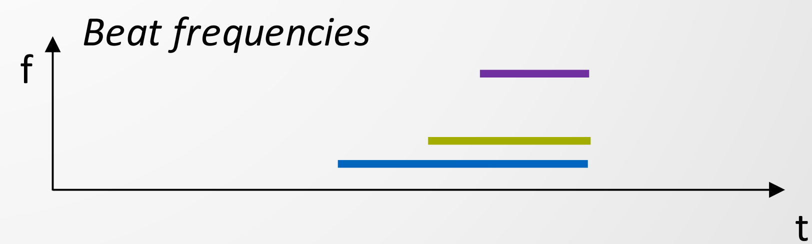
FMCW Radar (1)

Simultaneous Tx and Rx of Δf frequency sweep

Reception delay $\boldsymbol{\tau}$ and Doppler shift $\boldsymbol{f_D}$

Tx/Rx frequency mix ($\otimes$) yields *beat signal*





FMCW Radar (2)

Beat signal spectrum
is called **range profile**

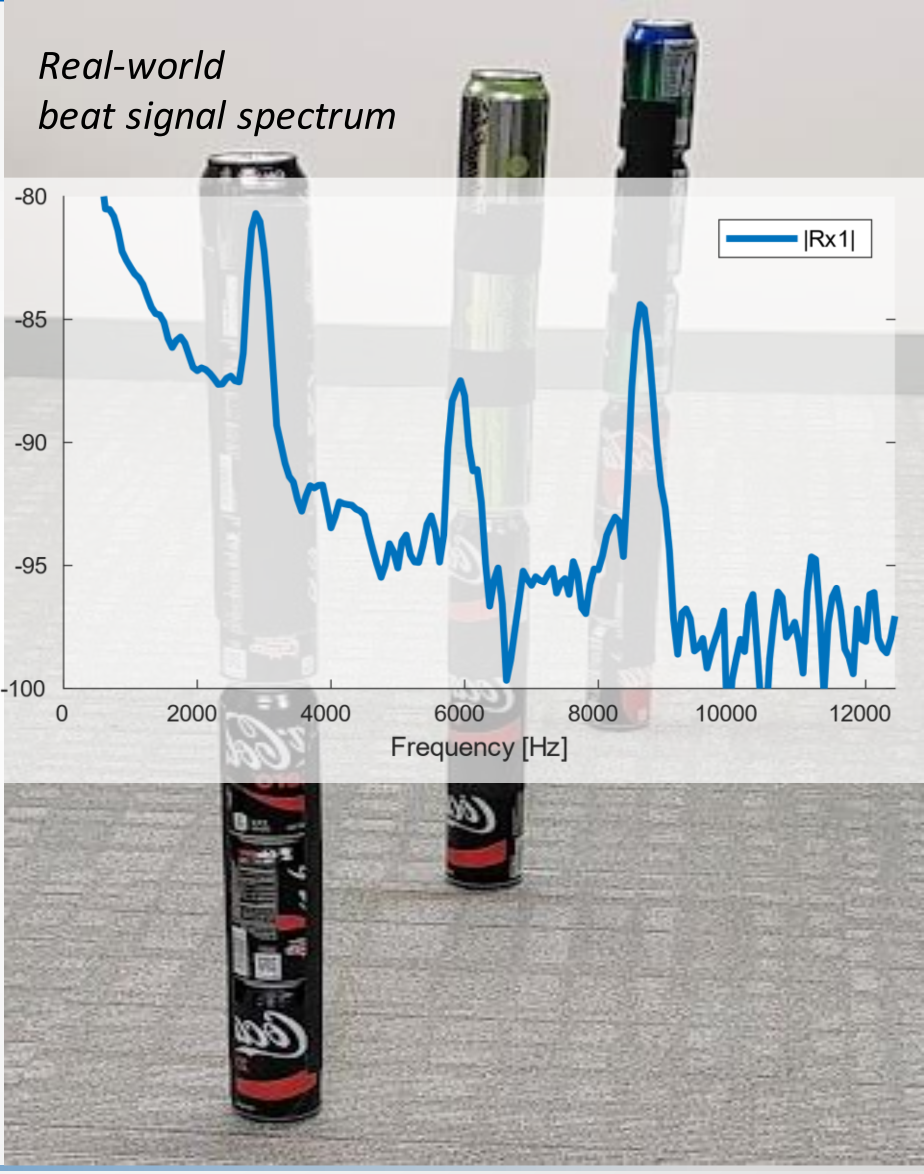
Range-frequency relation:

$$R = \frac{cT_d}{2\Delta f} f_R$$

Range resolution:

$$\mathrm{d}R = \frac{c}{2\Delta f}$$

with
sweep duration T_d
and bandwidth Δf

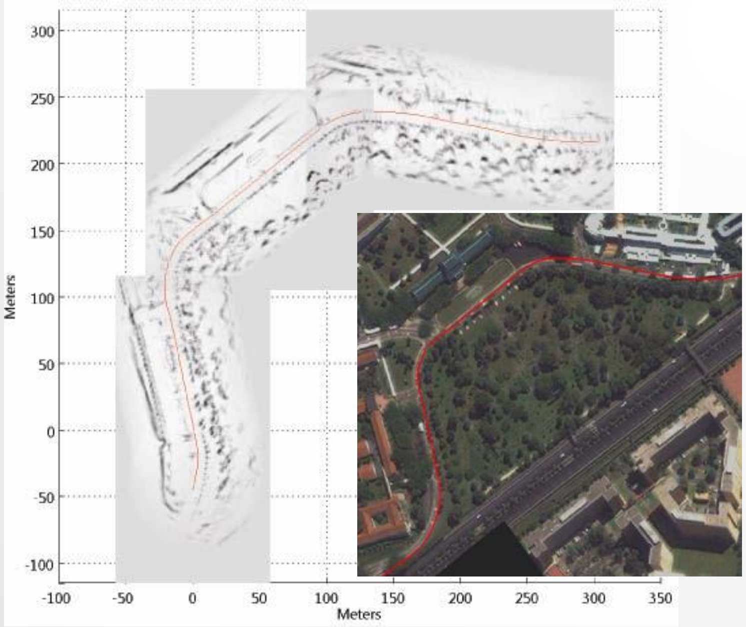


Related Work: Scanning Radar

Scanning Radar

Narrow beam shape samples all directions

Design complexity, Mechanical maintenance



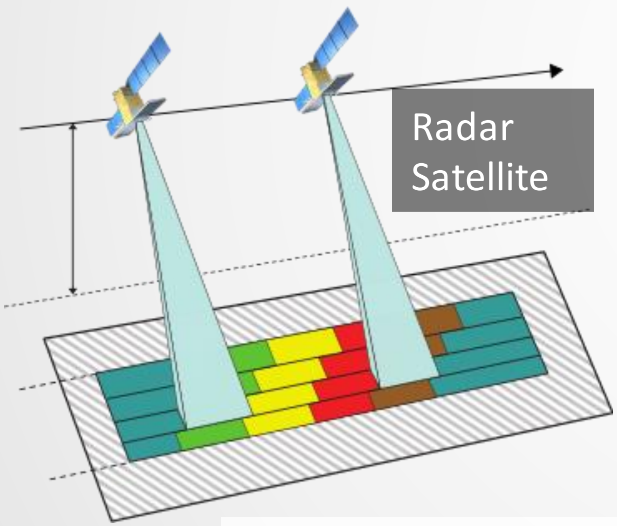
Adams, M. (2015). Robotic Navigation - Experience Gained with RADAR. 2nd Workshop on Alternative Sensing for Robot Perception at IROS 2015. Retrieved from https://www.rit.edu/kgcoe/iros15workshop/papers/IROS2015-WASRoP-Invited-01-slides.pdf

Related Work: SAR

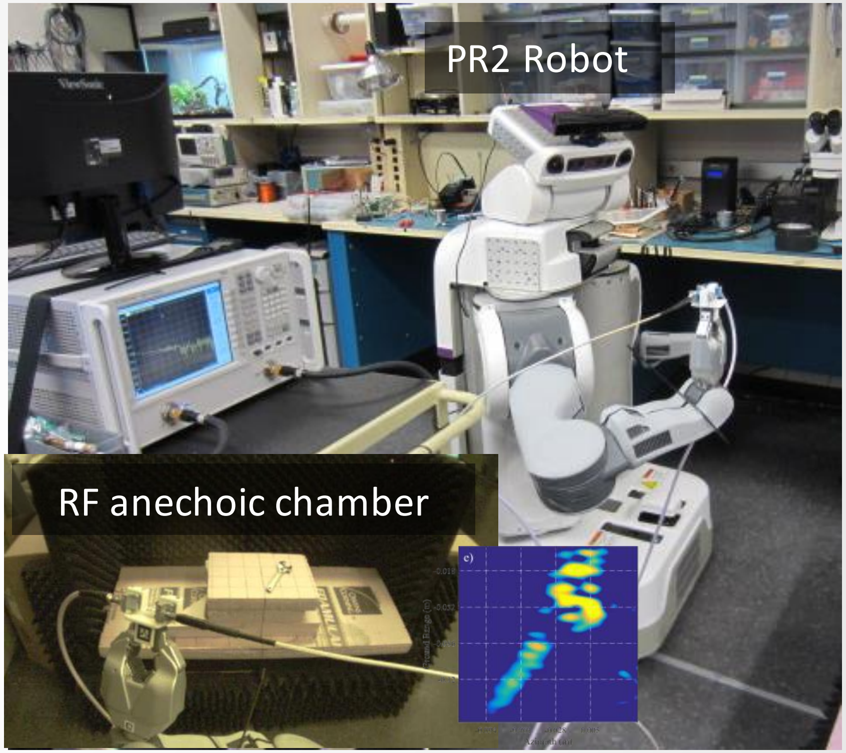
Synthetic Aperture Radar

SAR is great for imaging a scene from the side,

But only on straight paths



Moreira, A., Prats-Iraola, P., Younis, M., Krieger, G., Hajnsek, I., & Papathanassiou, K. P. (2013). A tutorial on synthetic aperture radar. IEEE Geoscience and Remote Sensing Magazine. https://doi.org/10.1109/MGRS.2013.2248301



Watts, C. M., Lancaster, P., Pedross-Engel, A., Smith, J. R., & Reynolds, M. S. (2016). 2D and 3D millimeter-wave synthetic aperture radar imaging on a PR2 platform. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 4304–4310). IEEE. https://doi.org/10.1109/IROS.2016.7759633

Reprojection Mapping

Benefit:

- Lower cost with *scanless* sensor

Requirements:

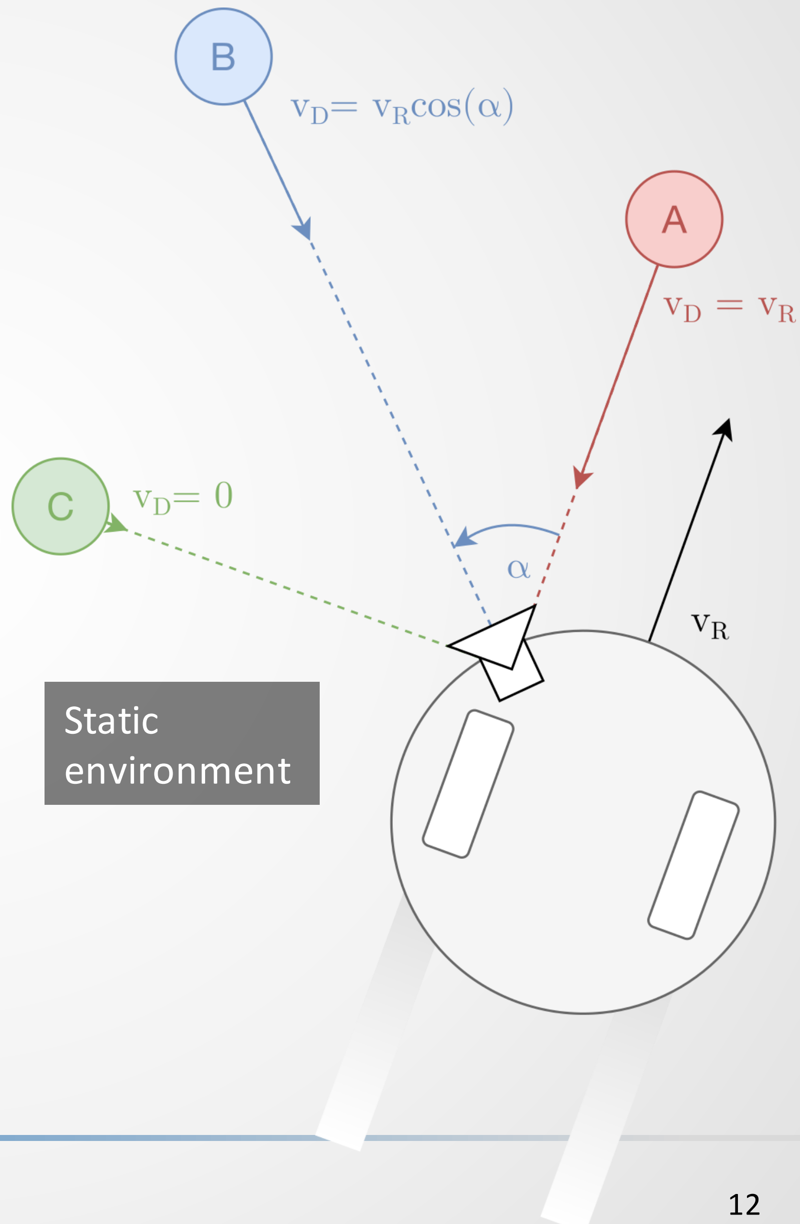
- Static environment
- Moved range sensor
- Known radar location

https://wikimedia.org/wiki/File:Radar_warning_road_sign_on_the_**Golden_Gate_Bridge**_99.jpg

Reprojection Geometry (Side)

Find
reprojection angle $\boldsymbol{\alpha}$
from
Doppler speed $\boldsymbol{v_D}$
in relation to
Radar speed $\boldsymbol{v_R}$

$$\boxed{\alpha = \arccos\left(\frac{v_D}{v_R}\right)}$$

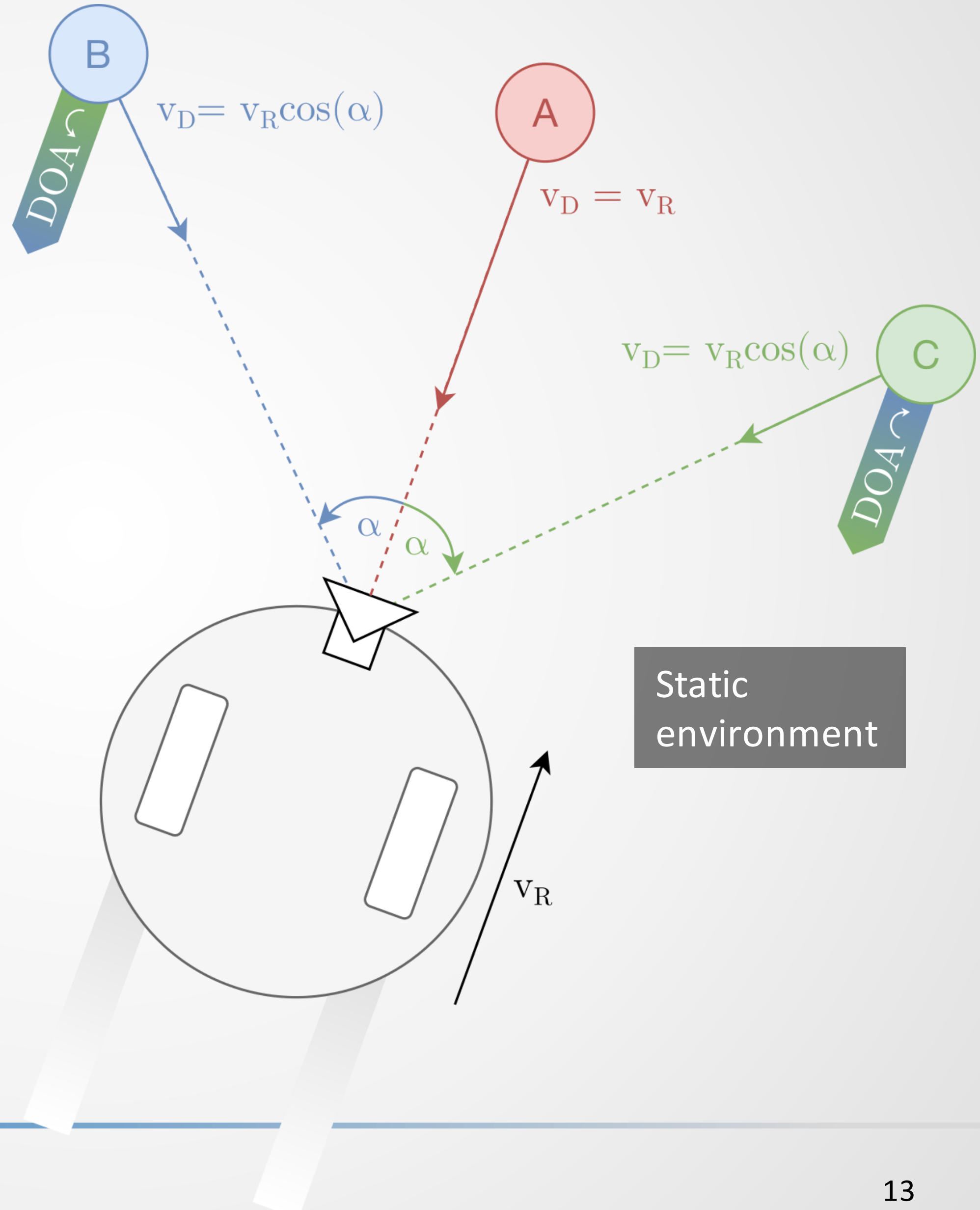


Reprojection Geometry (Forward)

Reprojection angle has ambiguities:

$$\alpha = \pm \arccos\left(\frac{v_D}{v_R}\right)$$

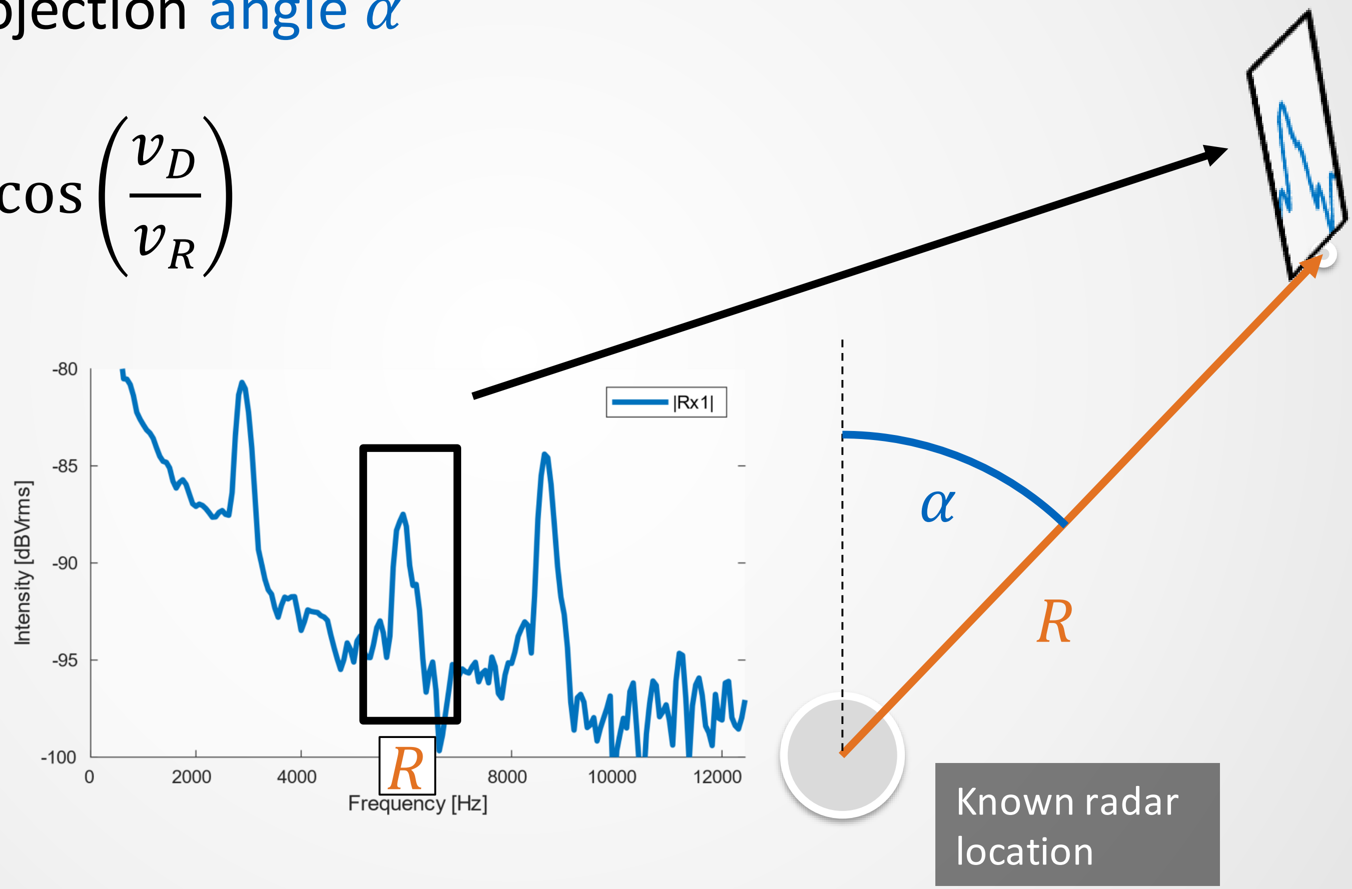
→ Direction of Arrival



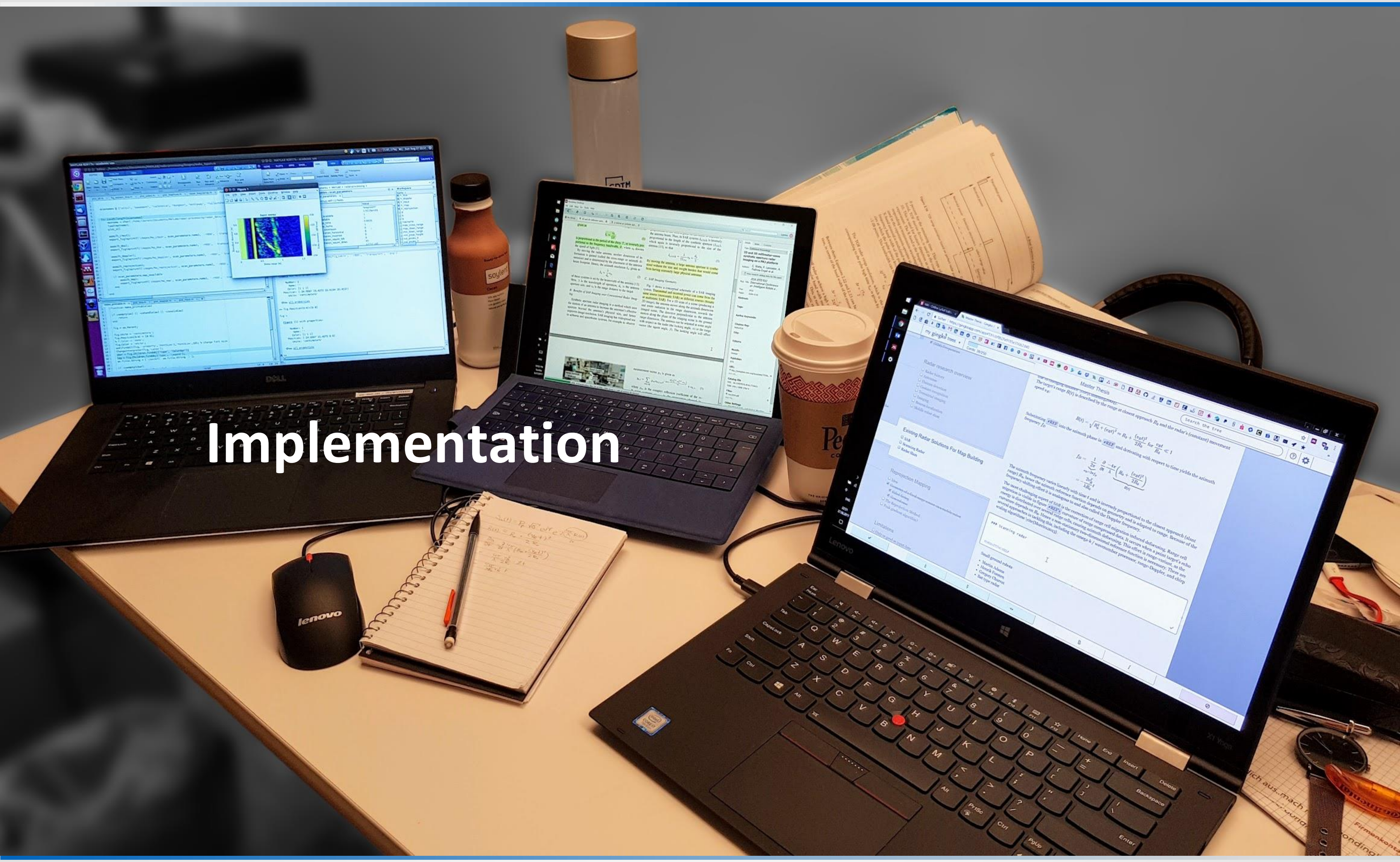
Reprojection Mapping

Reproject peak echo intensities at range R, reprojection angle α

$$\boldsymbol{\alpha} = \arccos\left(\frac{v_D}{v_R}\right)$$

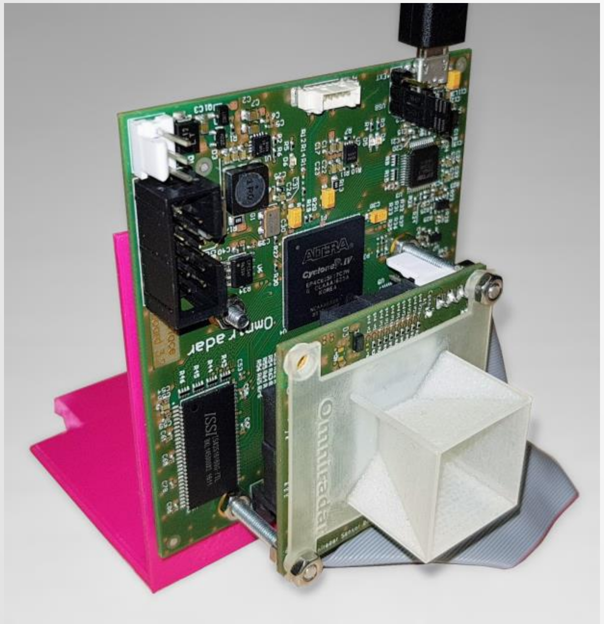


Implementation



Hardware Base

Robot Base	Computing	Lidar	RGBD
			
http://files.yujinrobot.com/Kobuki/marketing/icra_roscon/rollup_banner_0418_ver%20a1.pdf	https://wikimedia.org/wiki/File:Hardkernel_Odroid_XU4_Board.jpg	https://www.slamtec.com/en/Lidar/A1	https://orbbec3d.com/astra-mini/



Radar sensor:
Omniradar RIC60A

f_C = 60 GHz (ISM)
Δf = 7 GHz

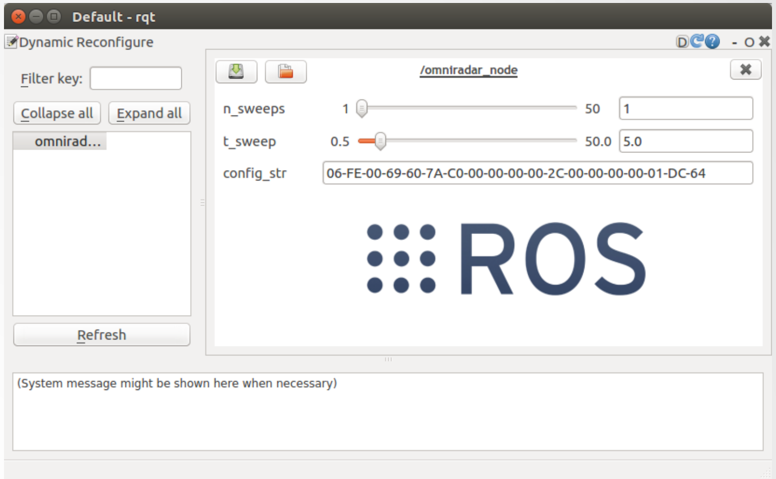
On-Chip antennas:
1 Tx, 2 Rx

Radar Driver

Port of Omniradar's
Windows MEX

New C++ library bindings

Rosnode with Dyn Reconf



RIC60A FPGA → FTDI D2XX → Rosnode → Rosbag

http://www.ros.org/press-kit/

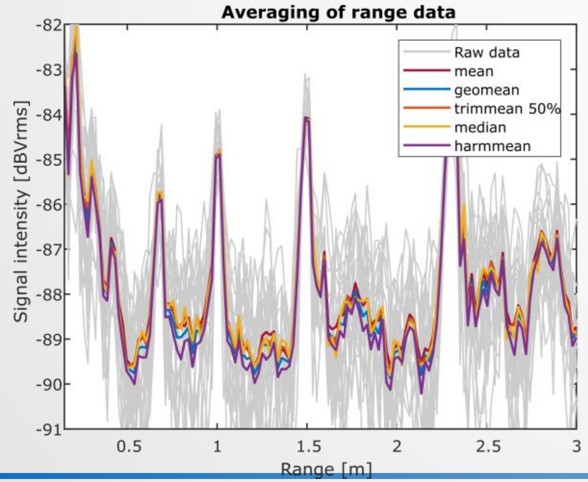
Data preprocessing

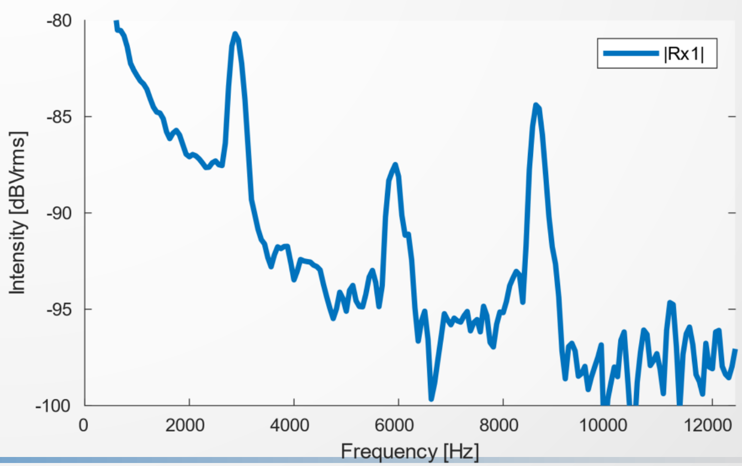
.bag to .mat conversion → Quick reload, smaller files

Odometry interpolation and drift correction → Precise, correct **radar location**

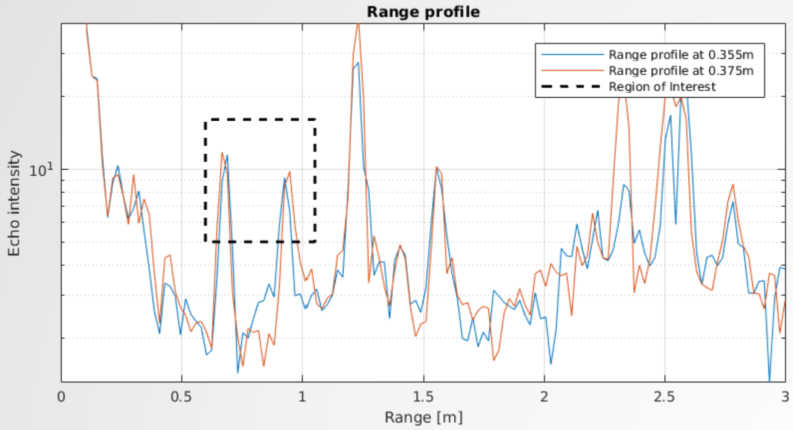
Cross-range averaging → **Higher SNR**, clear peaks

Range compensation → Reduce Tx crosstalk

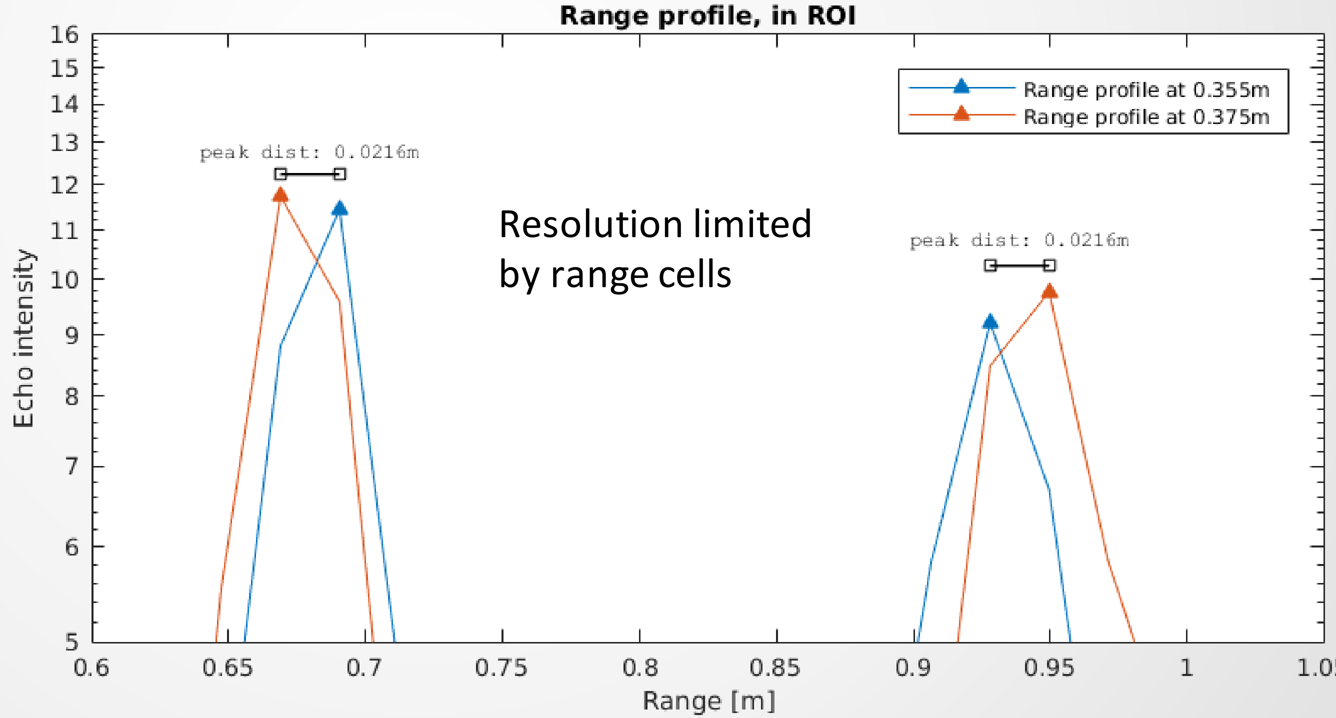




Doppler Estimation: Peak Gradient



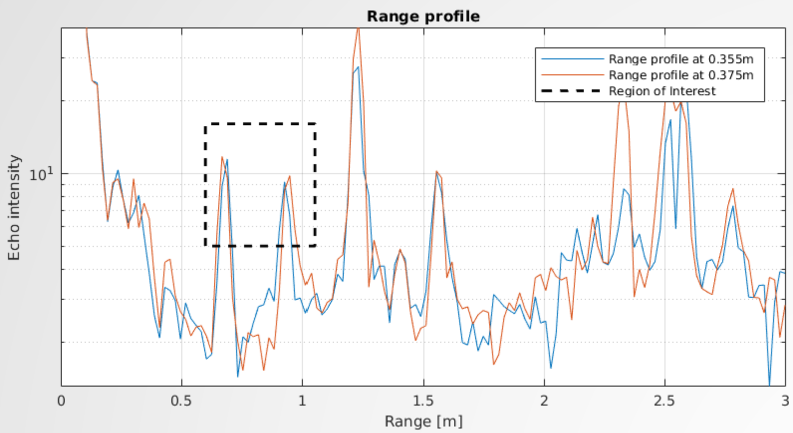
FMCW Doppler res. 2 m/s
→ Doppler from peak gradient

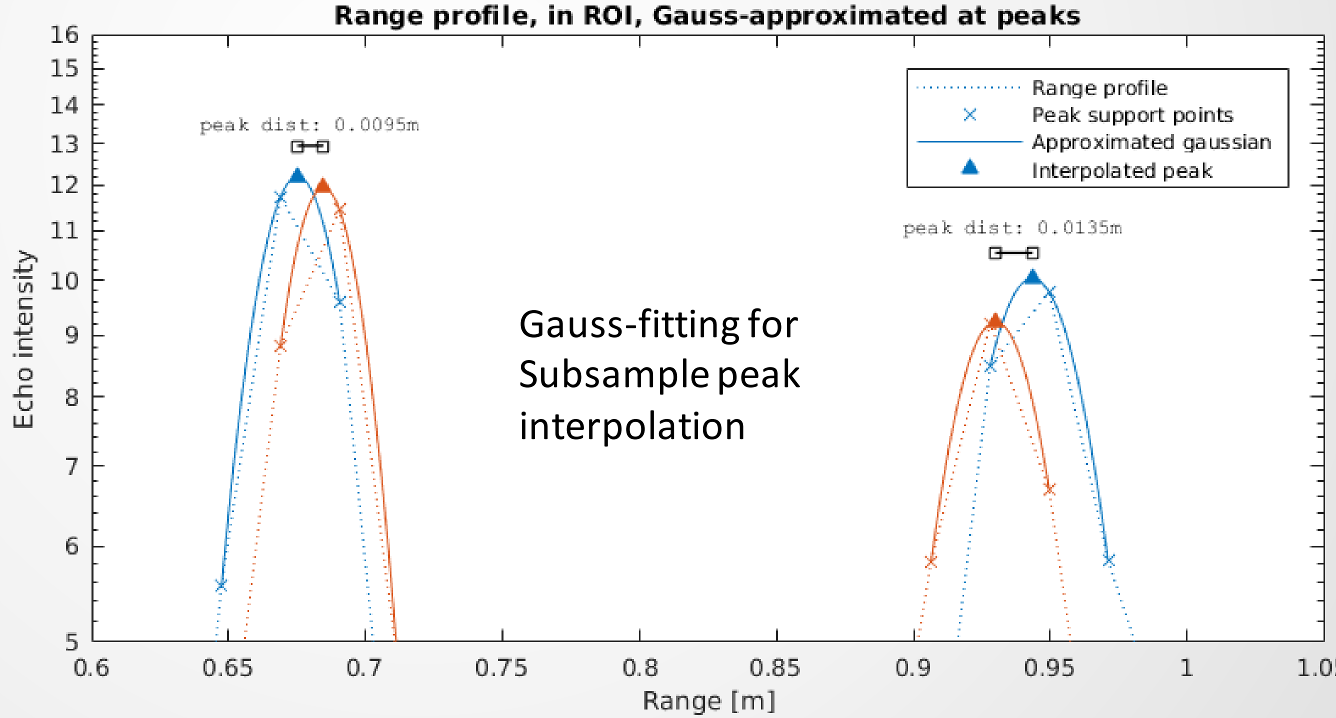


Resolution limited by range cells

Doppler Estimation: Peak Gradient

FMCW Doppler res. 2 m/s
→ Doppler from peak gradient



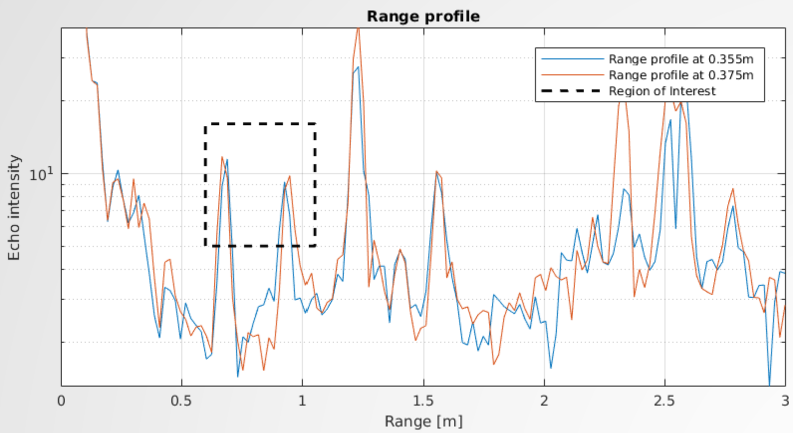


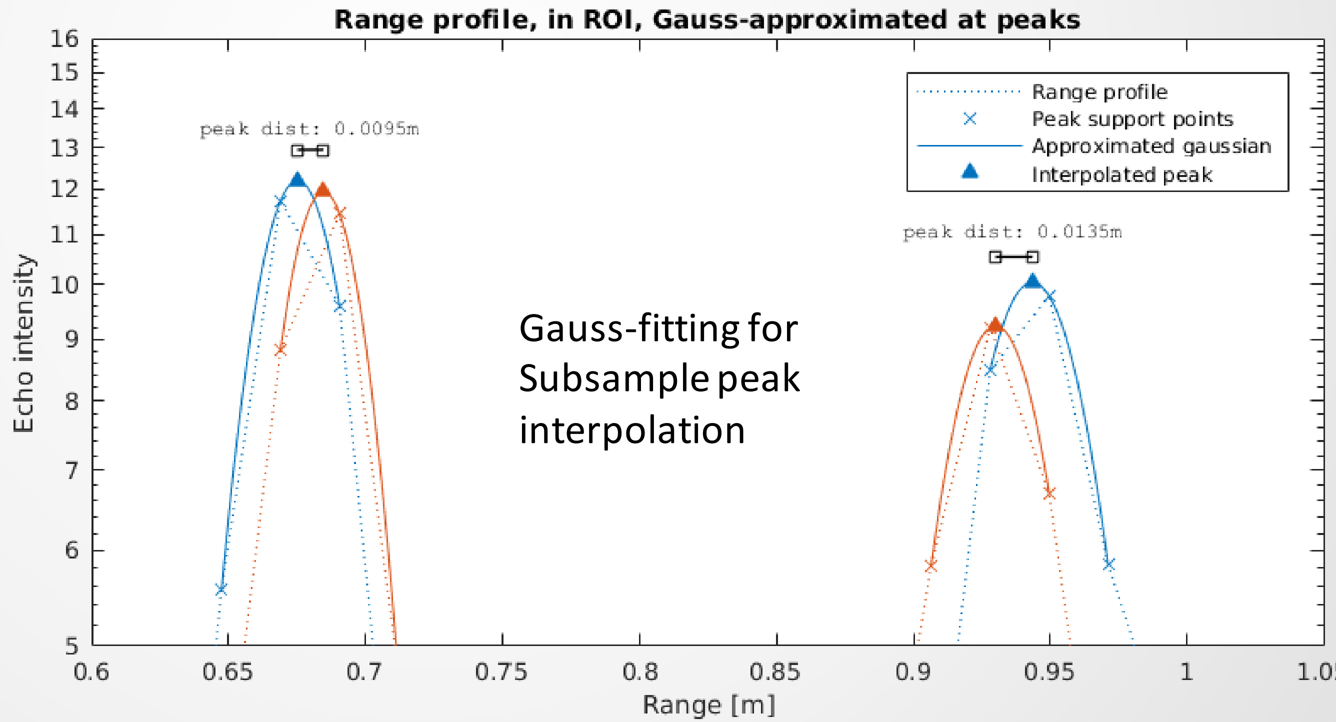
Gauss-fitting for
Subsample peak
interpolation

Doppler Estimation: Peak Gradient

FMCW Doppler res. 2 m/s

→ Doppler from peak gradient



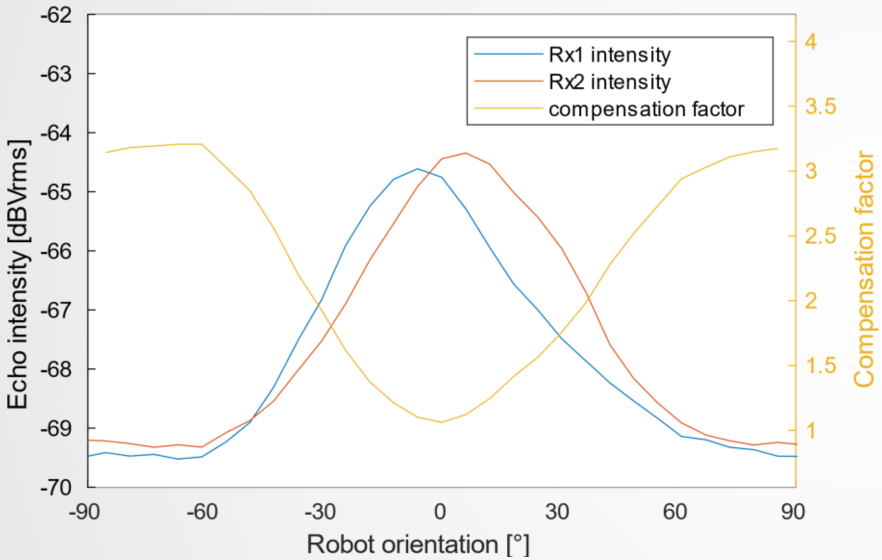


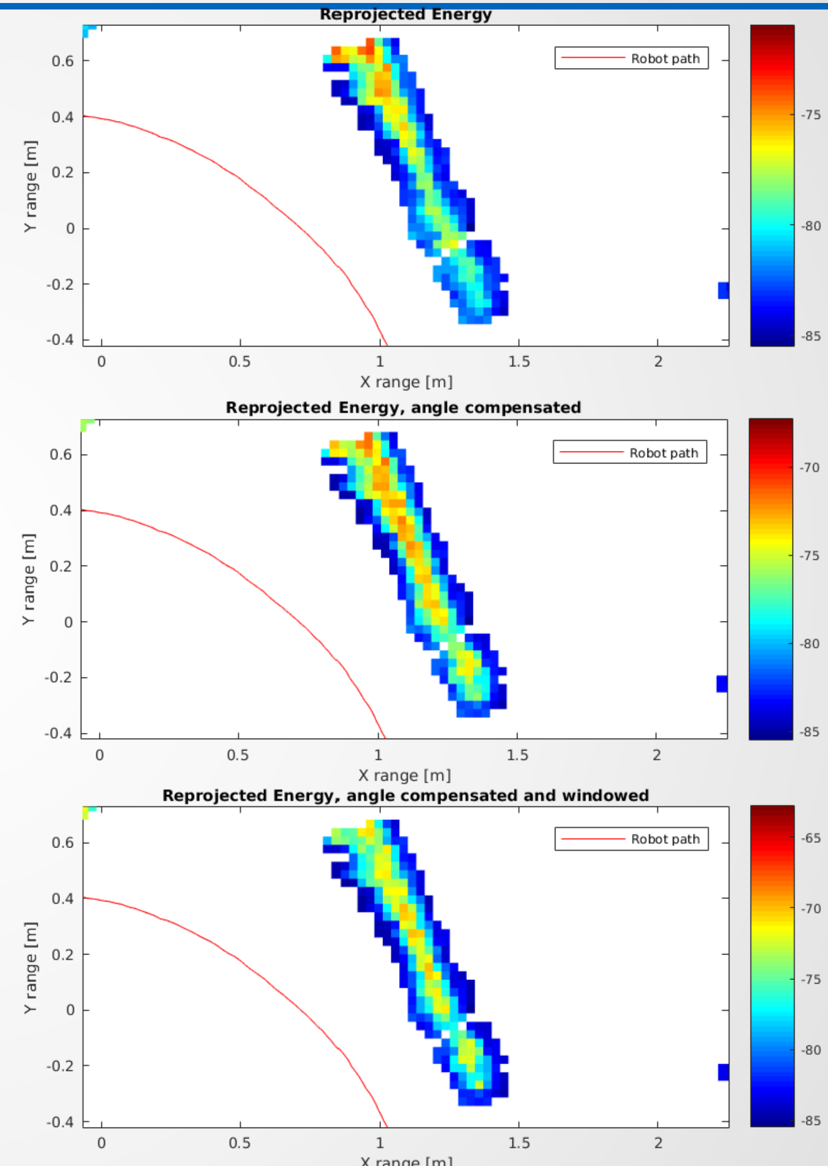
Parameters:

- Min. intensity
- Range change
- Intensity change

Angle sensitivity compensation

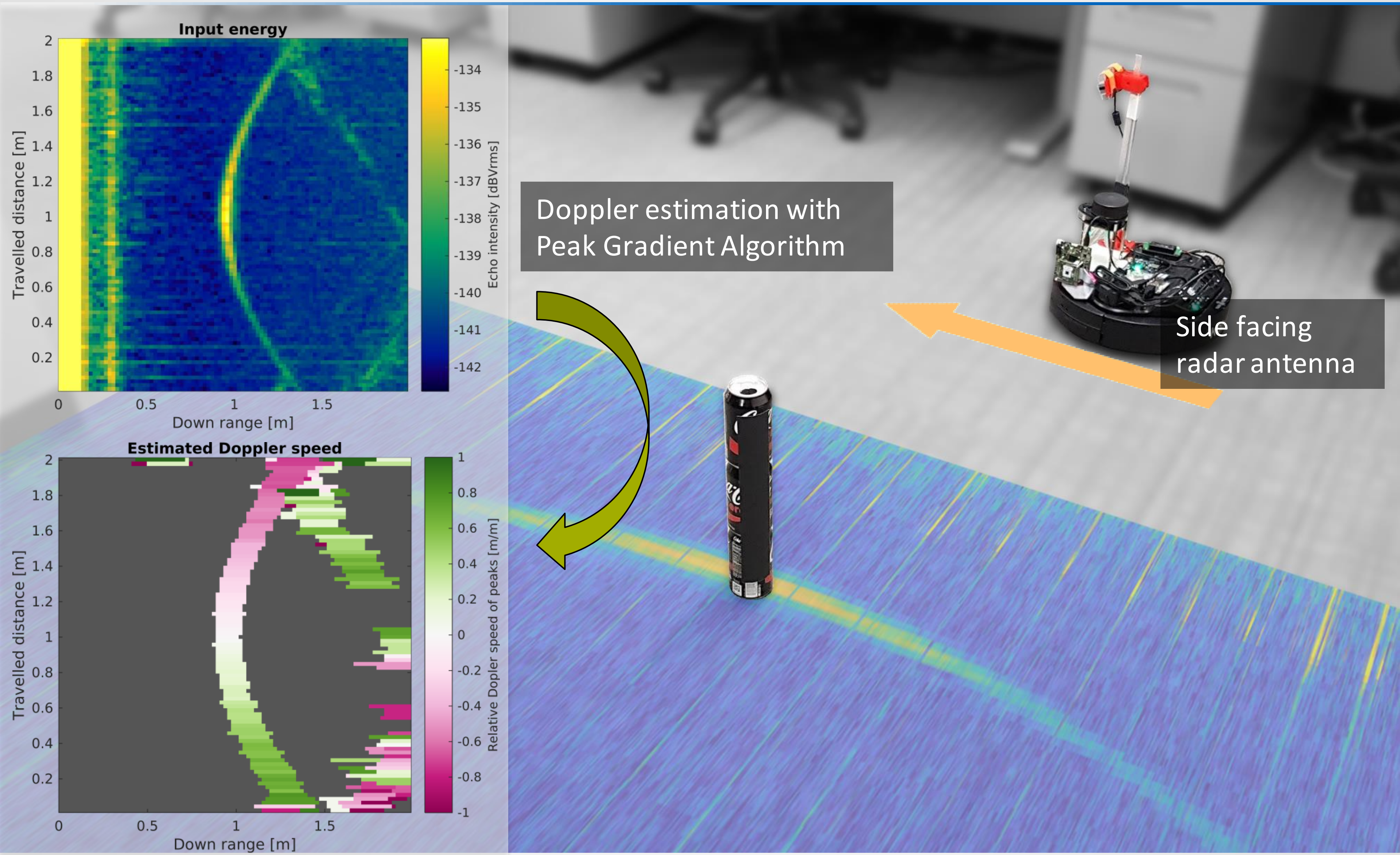
Antenna is orientation sensitive
→ measure and compensate



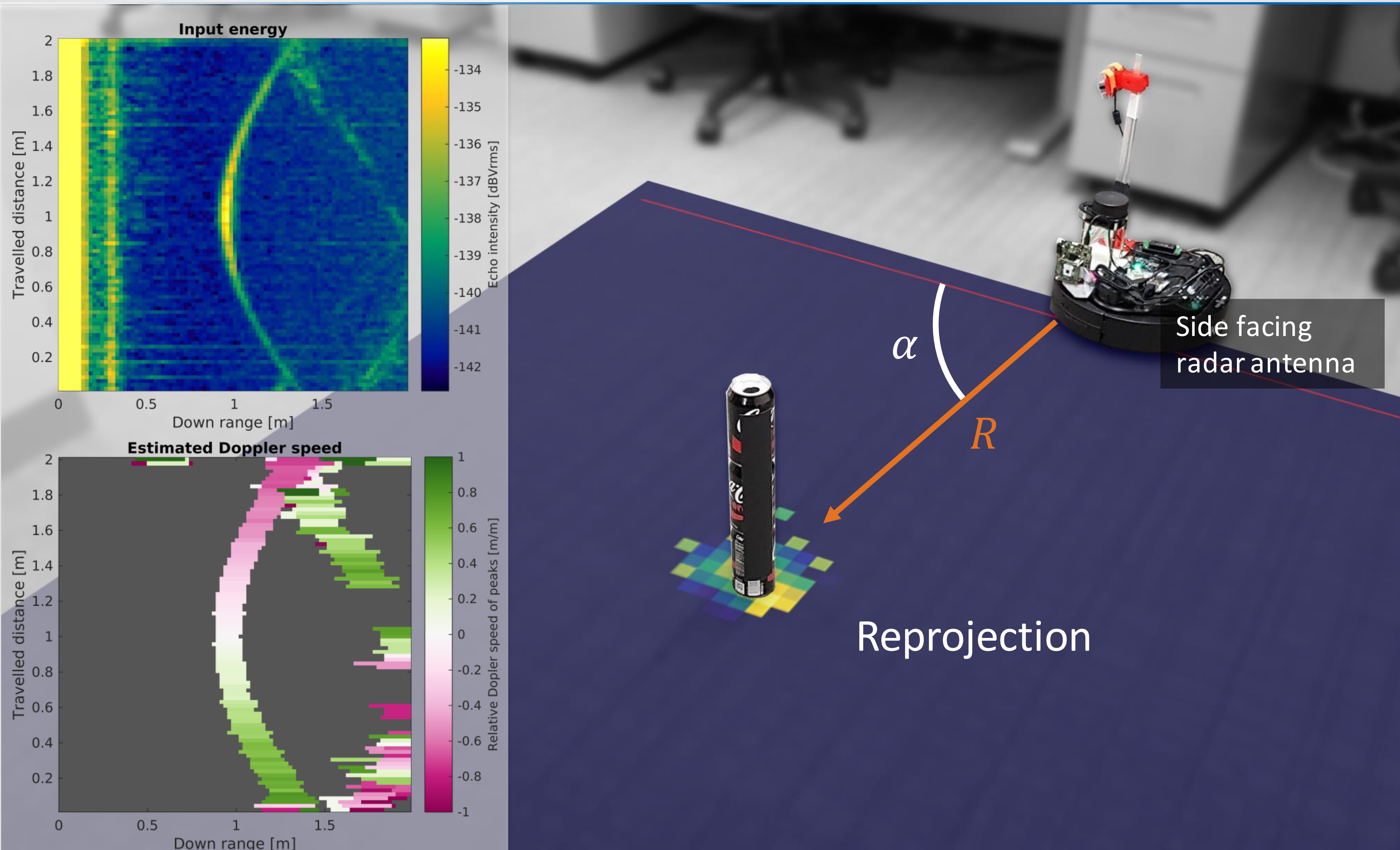


Results and Discussion

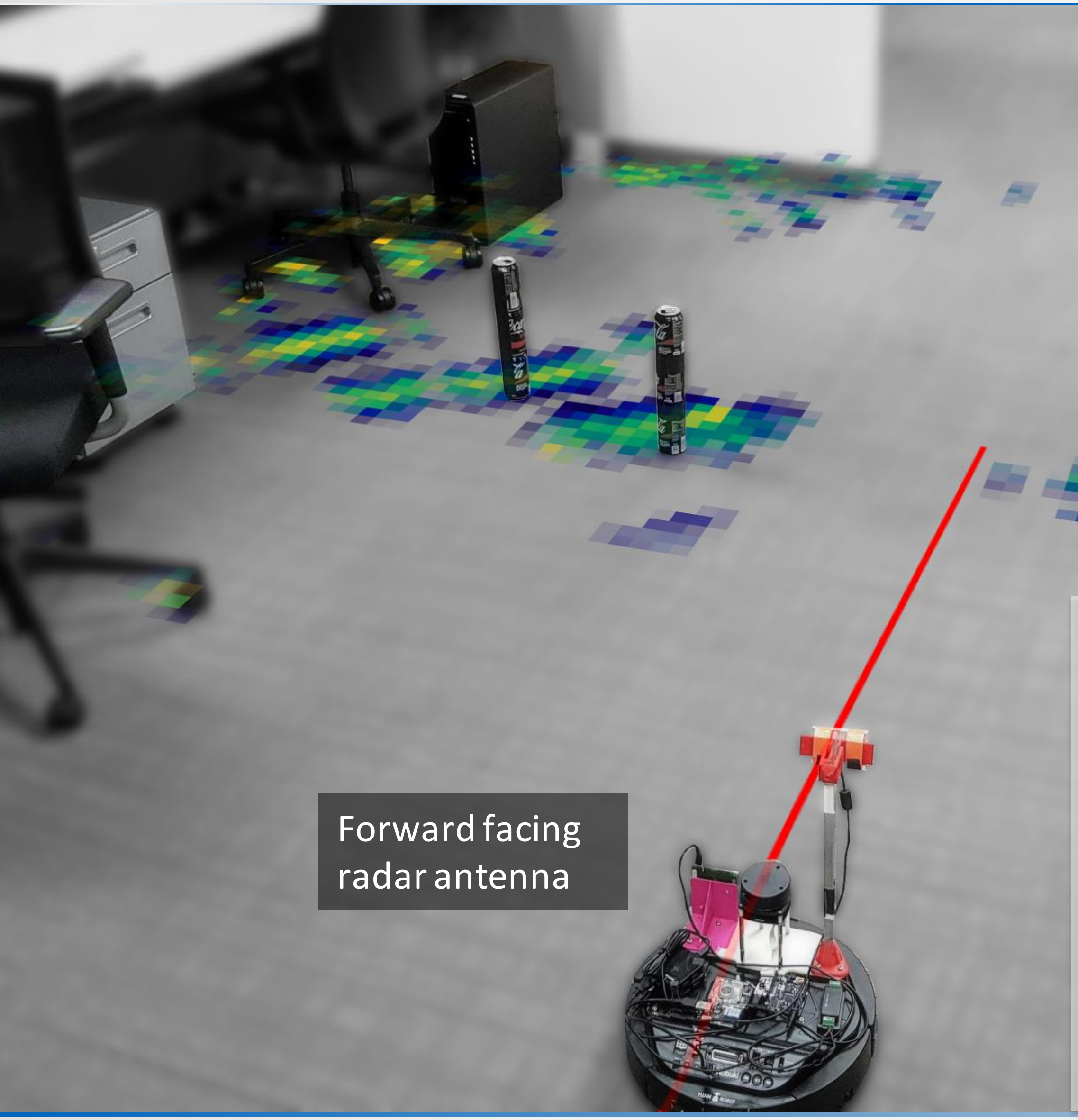
Reprojection Input

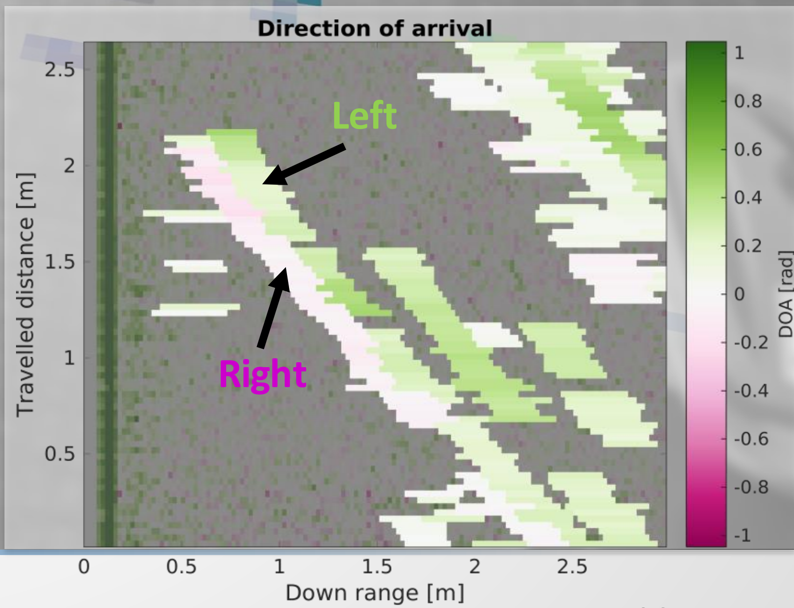


Reprojection Map

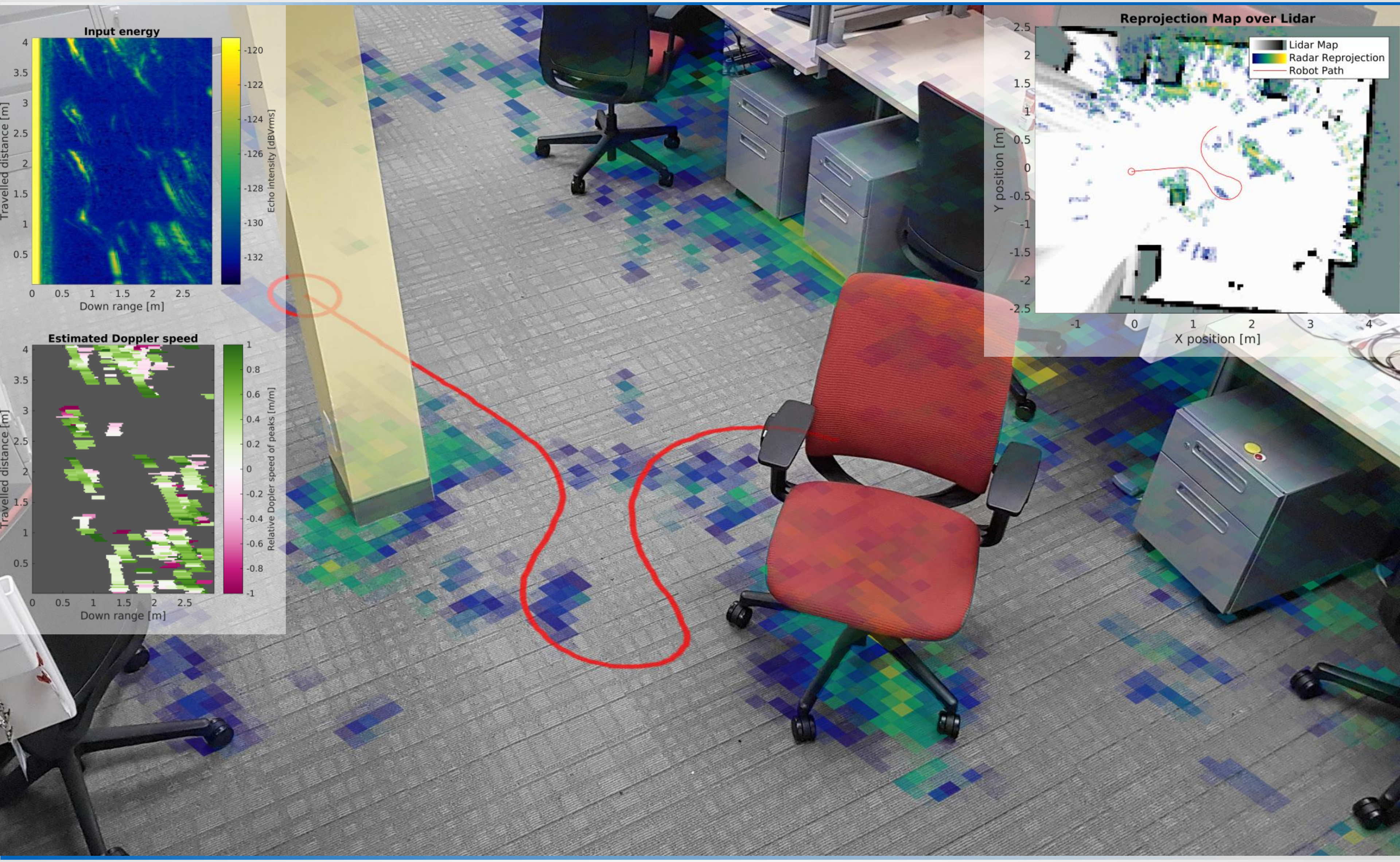


DOA Resolves Angle Ambiguity

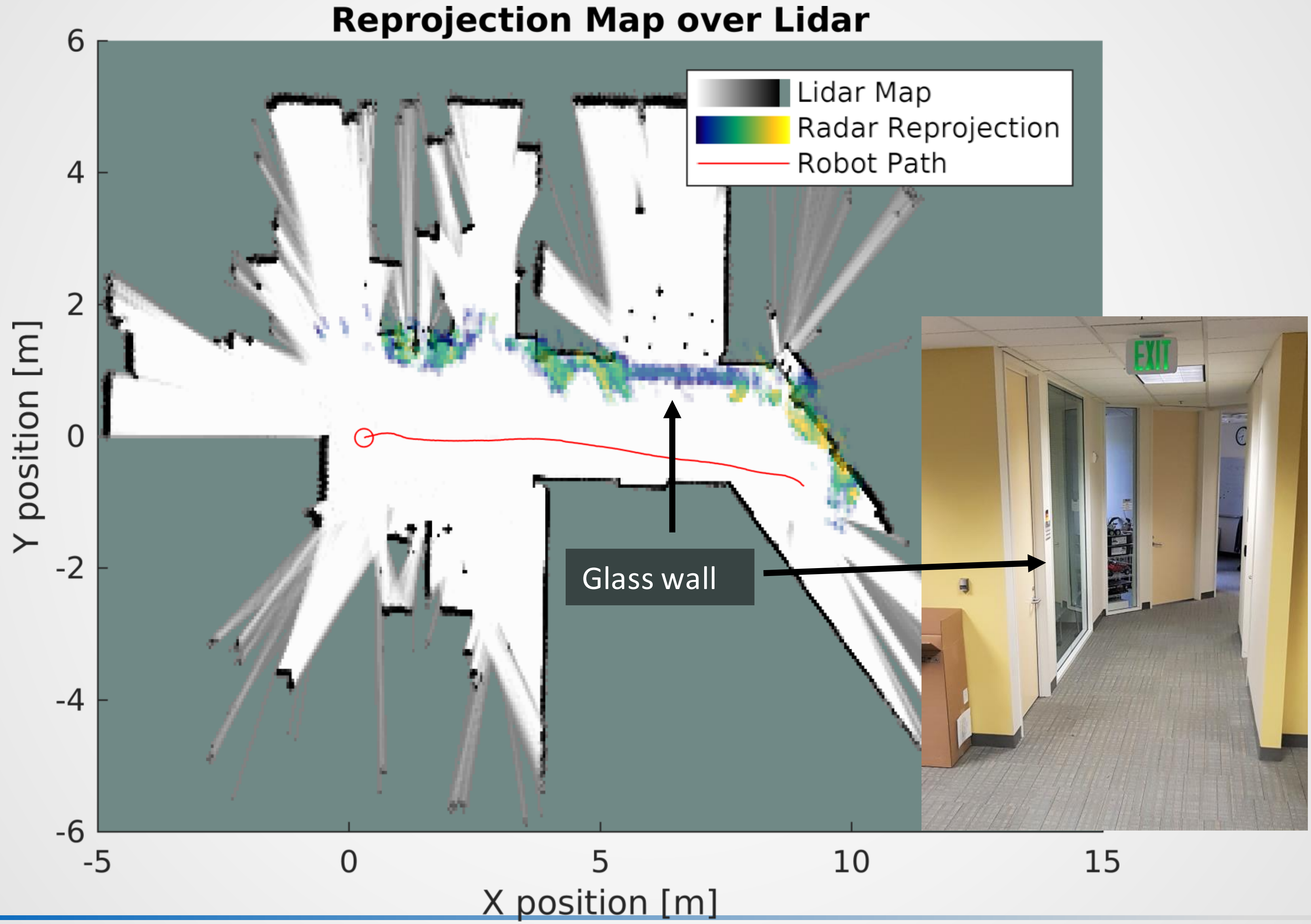




Chairlegs appear in radar map



Windows become visible



Conclusion

- Mobile robots still struggle to detect
some obstacles
- Implementation shows: reprojection mapping works within its limits
- Future work on
sonar version?

Thank you!

Get in touch at
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