Radar SLAM for Unmanned Surface Vehicle

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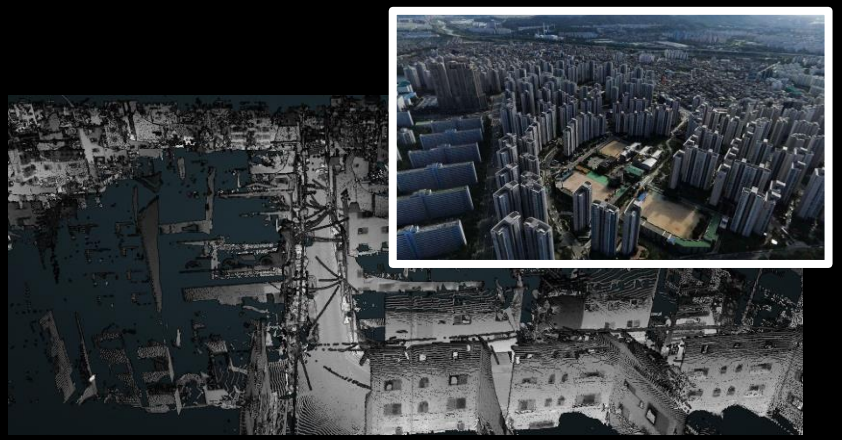
Bio

B.S. Mech. & Aero. Eng. SNU 2005
M.S. Mech. & Aero. Eng. SNU 2007
M.S. Elec. Eng. Univ. of Michigan 2011
Ph.D. Mech. Eng. Univ. of Michigan 2012
Civil & Env. Eng. KAIST 2014 – 2021
Mech. Eng. SNU, 2021 – present

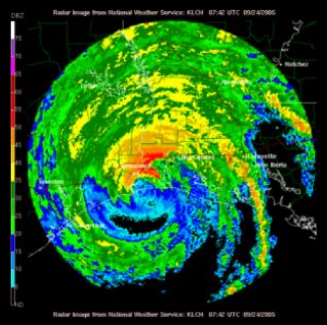
Research Interest

- Intelligent perception and mapping
- Autonomous robotic navigation
- Underwater imaging and navigation
- Sensor based 3D Modeling
- Spatiotemporal representation of 3D model



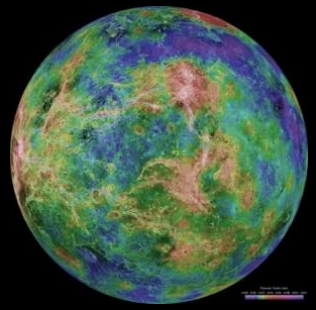
Brief Summary of Radars

- Radio detection and ranging (RADAR)
  - Transmission and reception of electromagnetic wave (1800s)



Weather [1]

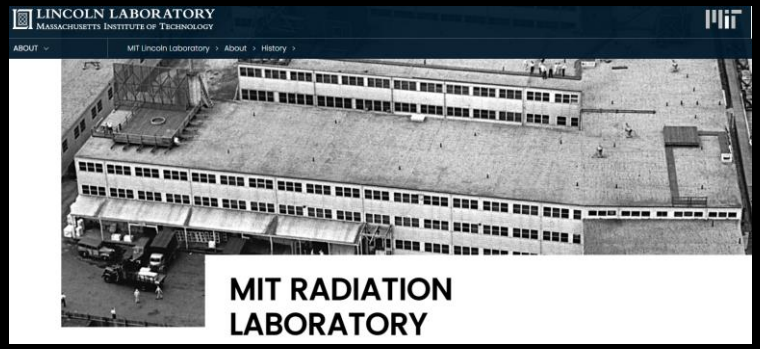
Military [2]



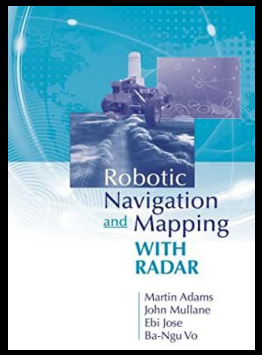
Radar map of Venus [3]

Police speed gun [4]

  - Early works mostly at military application during World War I and II



Plan Position Indicator (PPI) [5]



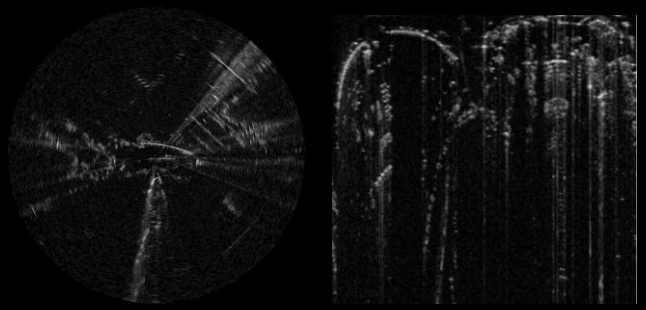
[1] https://public.wmo.int/
[2] https://www.dreamstime.com/
[3] https://sci.esa.int/
[4] https://www.radargunsales.com/
[5] Wikipedia

Radar for Extreme Environments

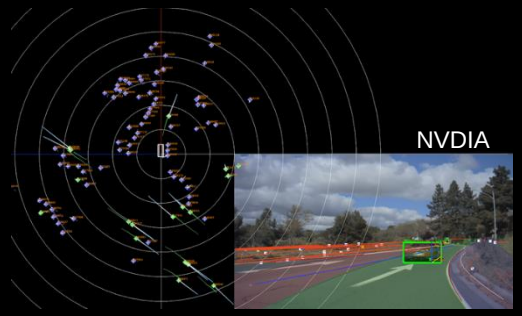
Popular Radar Types in Robotics

- Imaging radar
  - Output 200m range polar image

Navtech

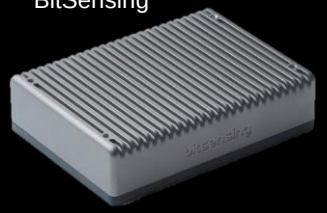


- 4D radar
  - Range & velocity of the object
  - Automotive radars



NVDIA

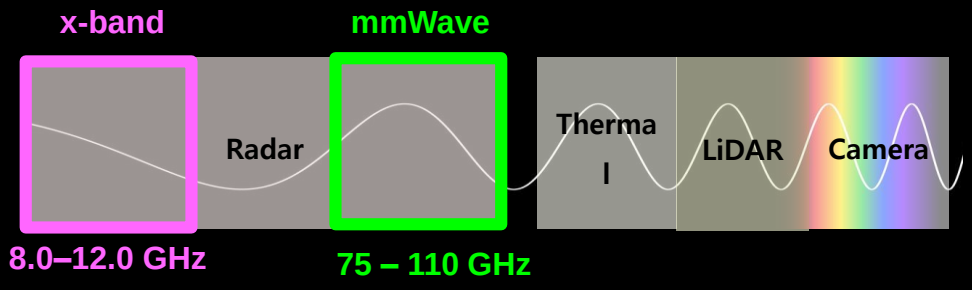
BitSensing

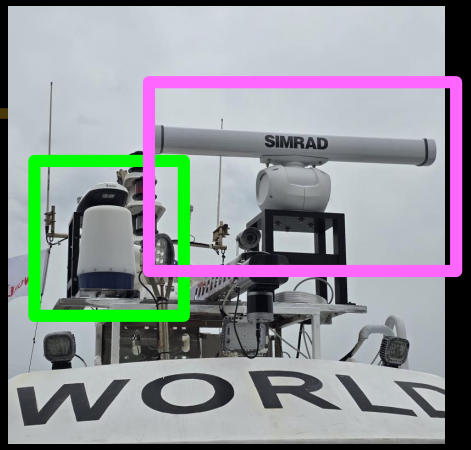


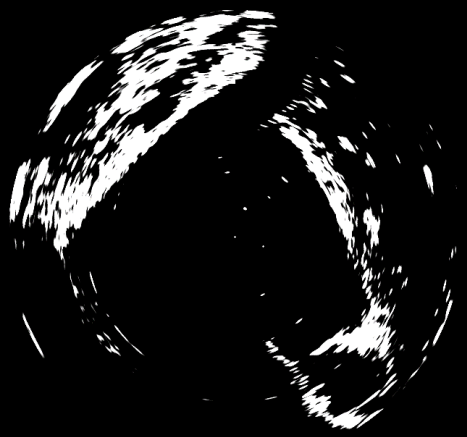
- Radar-on-chip

Texas Instruments

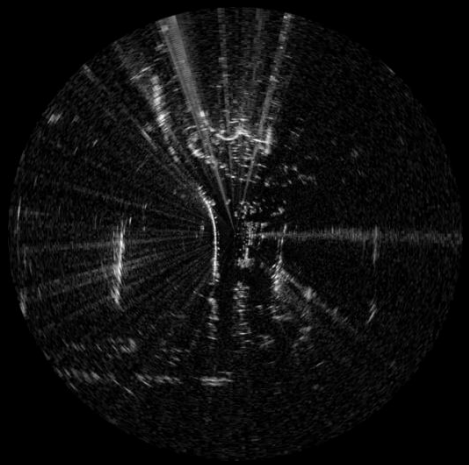
Radar Choice for Marine Robotics





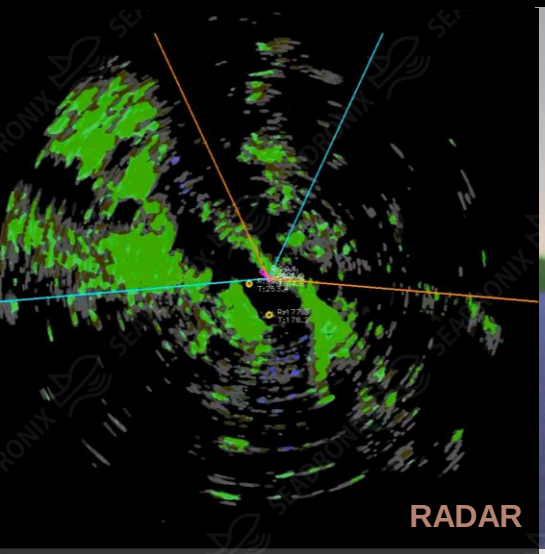


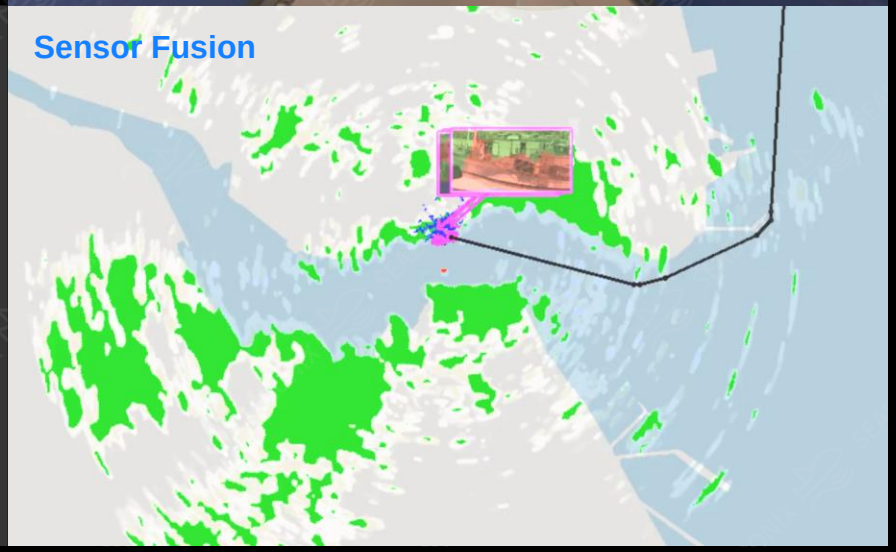
Marine Radar



mmWave Radar

Unmanned Surface Vehicles (USVs)





AI-powered solution for maritime industry

Core Technology
- Vision/RADAR-based Object Recognition
- Sensor Fusion
- Path Planning/Following

Product
- Advanced navigation assistance system for ship
- Autonomous system for ship&port

About SEADRONIX
- Established: 2015
- Selected to Forbes Asia 100 to Watch 2023
- CES Innovation Awards 2024
- Funding from Softbank Ventures Asia

For more:
https://www.seadronix.com

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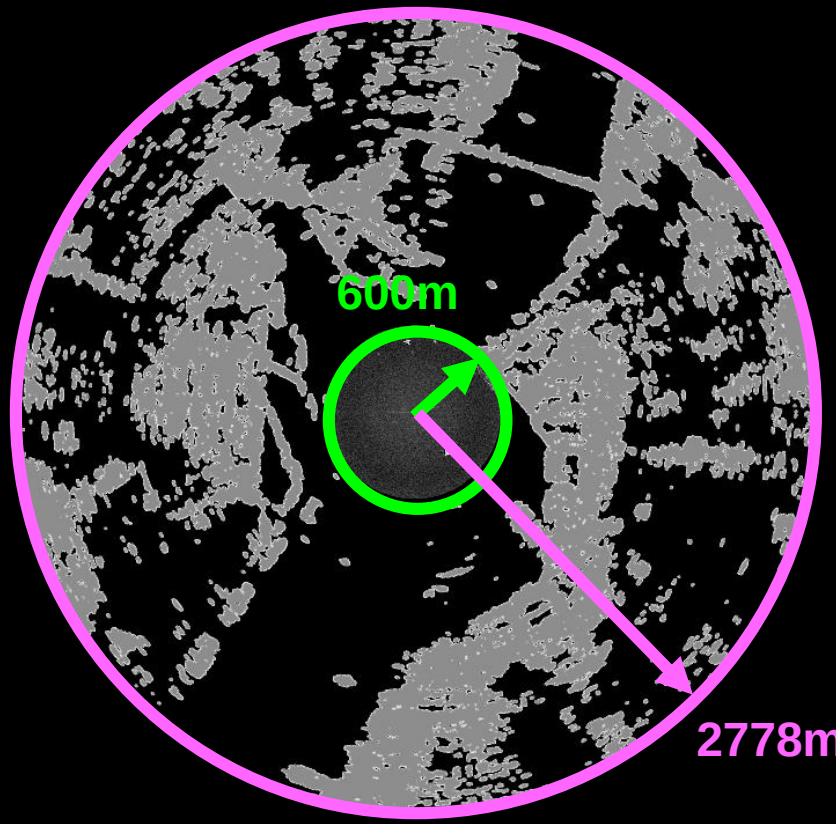
Two Imaging Radars for USV

Resolution? ↓
Frequency? ↓

Range? ↑



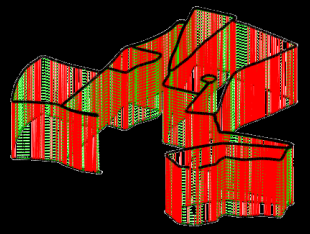
Resolution? ↑
Frequency? ↑

Range? ↓

Overview

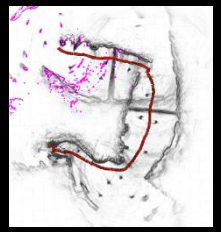
Radar Place Recognition

Radar PR using mmWave radar
Roto-Translational invariant PR



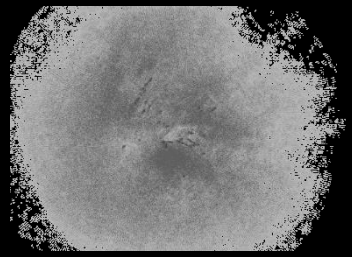
Maritime Radar Odometry

Radar odometry using xband radar
Definition of the Maritime Features



Maritime Radar SLAM

mmWave + xband radar
Point Ambiguity Reduction



RaPlace

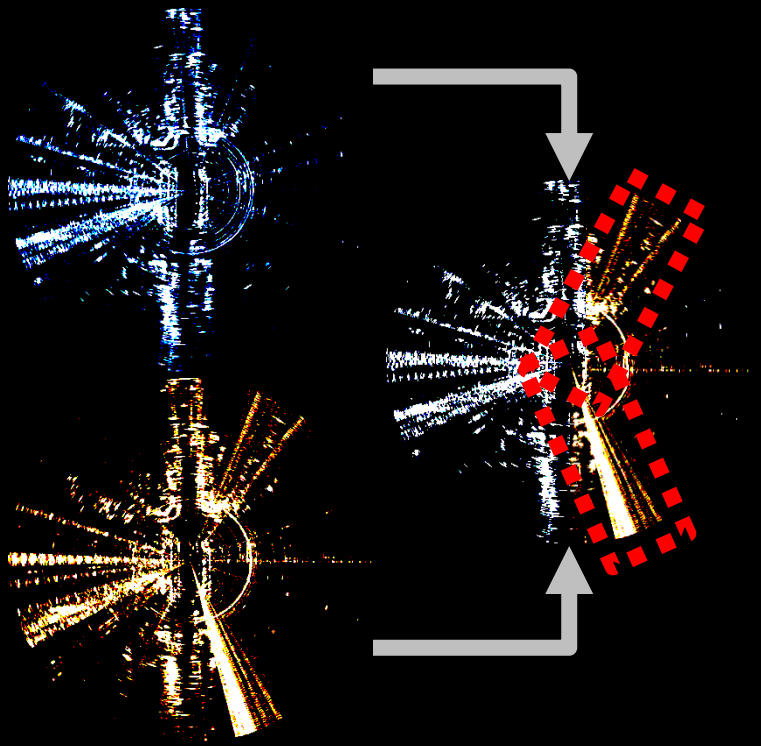
Marine Radar Place Recognition (IROS 23)

https://github.com/hyesu-jang/RaPlace

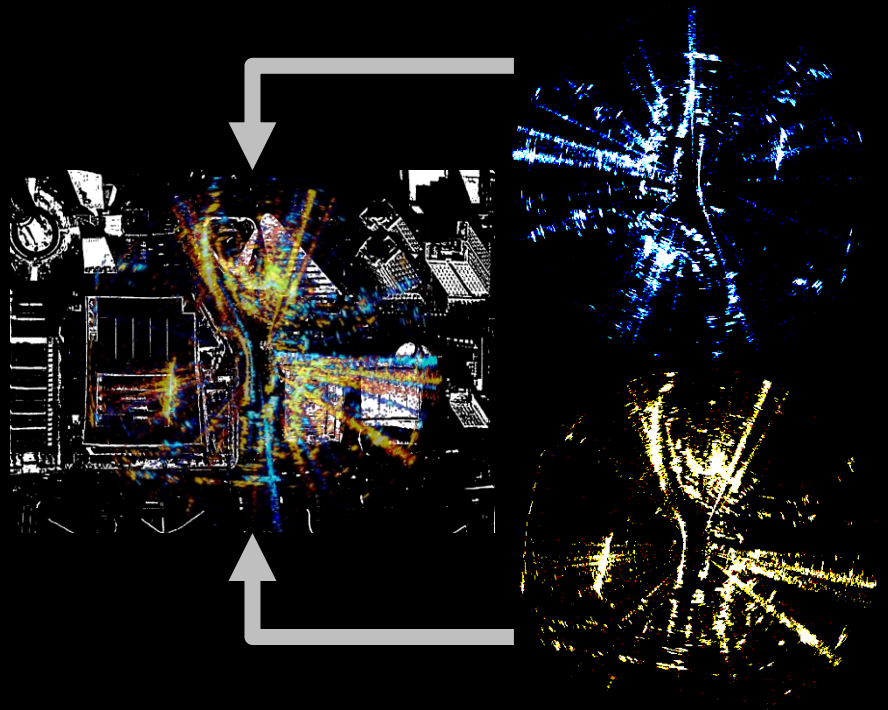
H. Jang, M. Jung and A. Kim, RaPlace: Place Recognition for Imaging Radar using Radon Transform and Mutable Threshold. IROS 2023

RaPlace: Radar Place Recognition


Radar Multipath Noise



Rotation & Translation Invariance



H. Jang, M Jung, and A. Kim, RaPlace: Place Recognition for Imaging Radar using Radon Transform and Mutable Threshold, IROS 2023.

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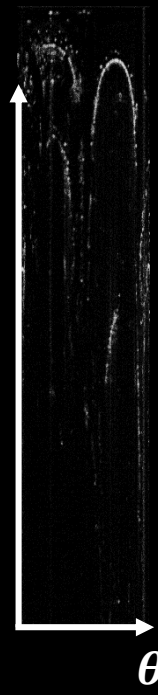
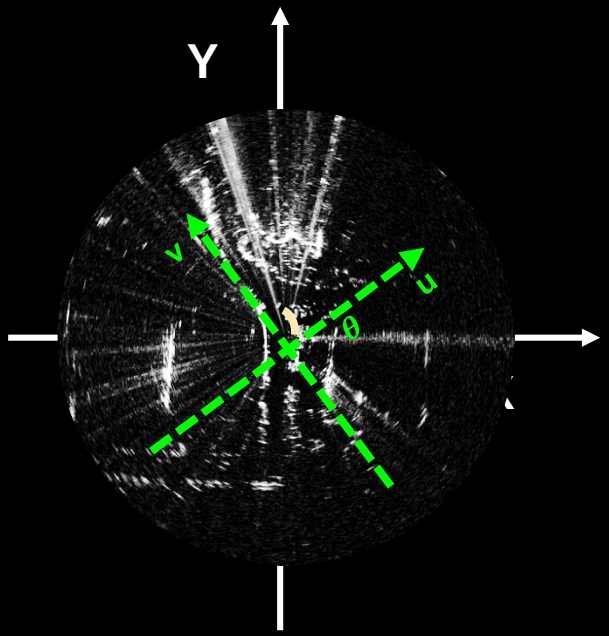
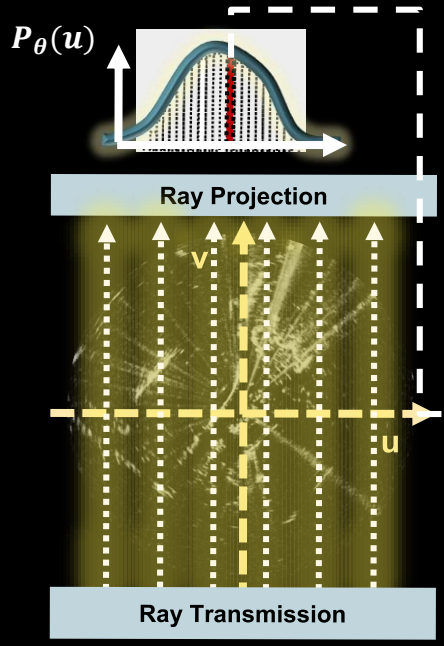
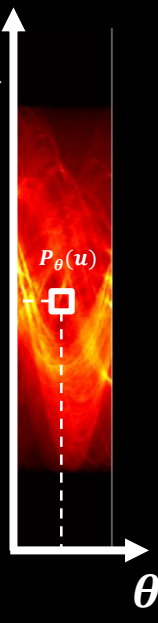
RaPlace

- Radon transform generates sinogram
  - Sinogram represents the accumulated value for each theta.







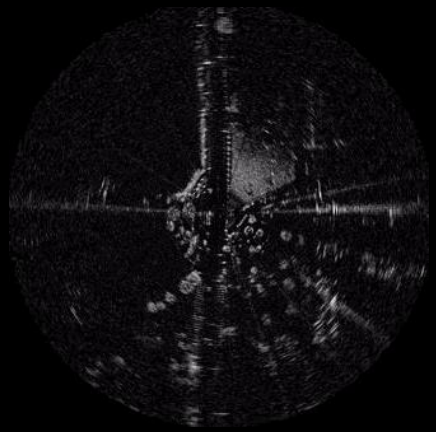


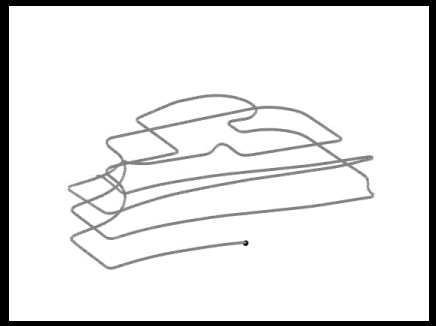
Polar | Cartesian | Sinogram

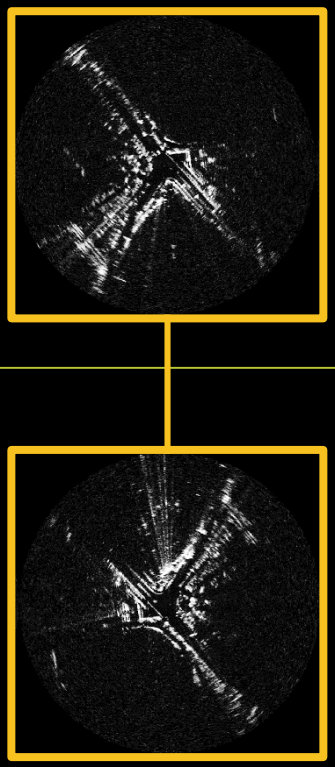
H. Jang, M Jung, and A. Kim, RaPlace: Place Recognition for Imaging Radar using Radon Transform and Mutable Threshold, IROS 2023.

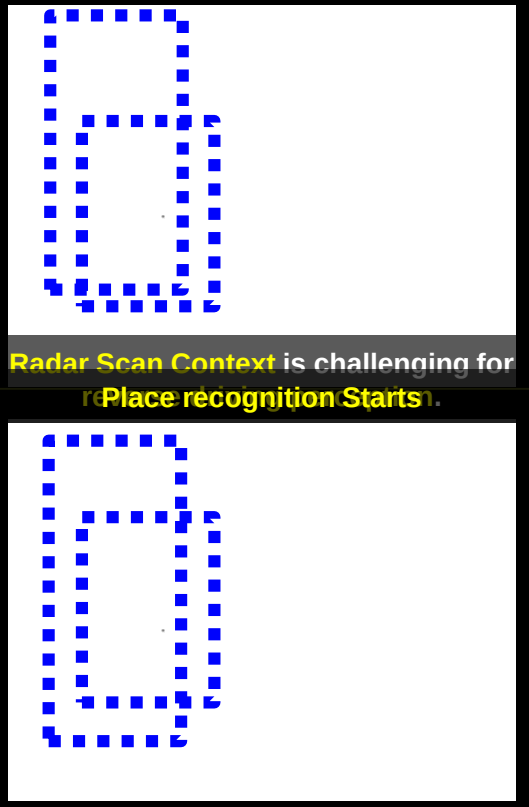
Evaluation – MulRan KAIST


common fail matched









Radar Scan Context is challenging for
Place recognition Starts

H. Jang, M Jung, and A. Kim, RaPlace: Place Recognition for Imaging Radar using Radon Transform and Mutable Threshold, IROS 2023.

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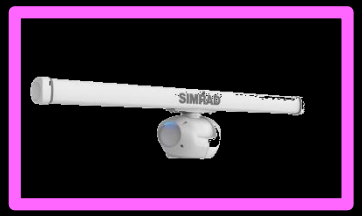


LodeStar

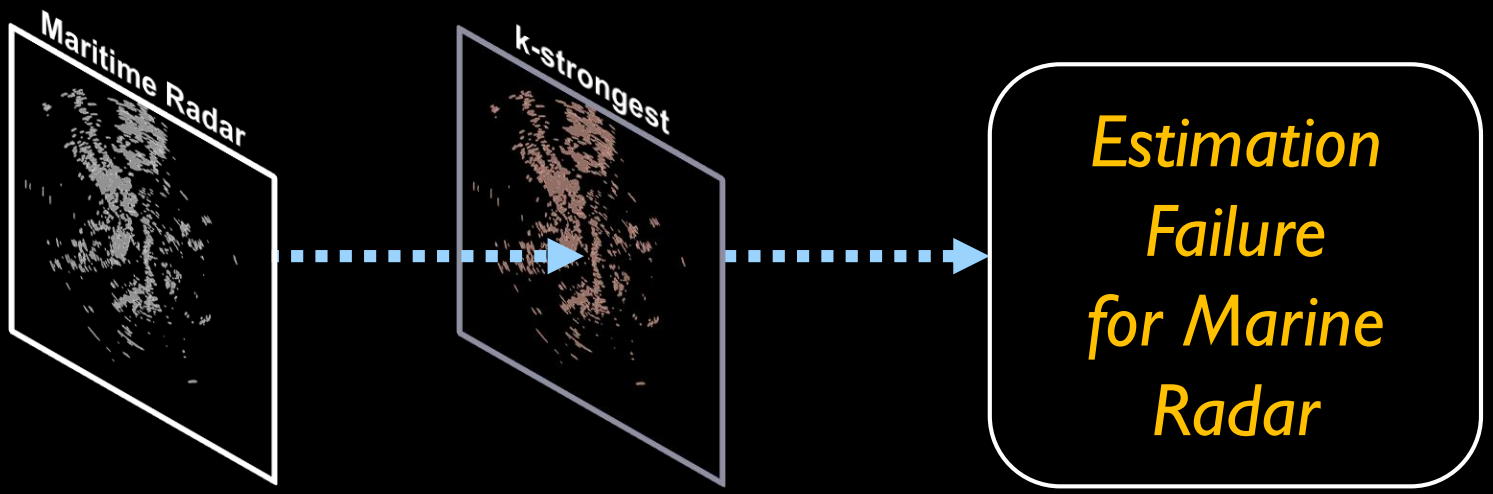
Imaging Radar Odometry for USV (RAL 24 / IROS 24)

https://github.com/hyesu-jang/LodeStar

H. Jang, M. Jung, M. Jeon and Ayoung Kim, LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry RA-L 2024

Maritime Radar Odometry

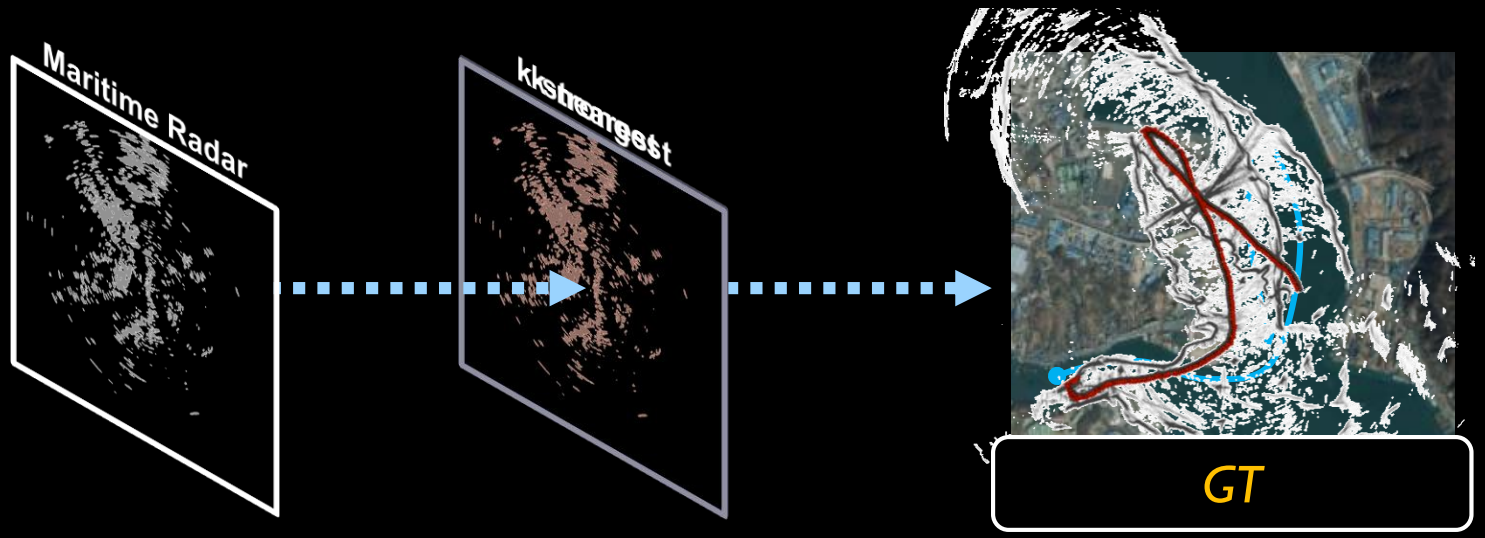




CFEAR, TRO 22

Hyesu Jang, Minwoo Jung, Myung-Hwan Jeon, Ayoung Kim "LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry." IEEE RAL 2024.

Maritime Radar Odometry



We need enhancement on orientation estimation!

Odom Failure under Large Rotation

Hyesu Jang, Minwoo Jung, Myung-Hwan Jeon, Ayoung Kim "LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry." IEEE RAL 2024.

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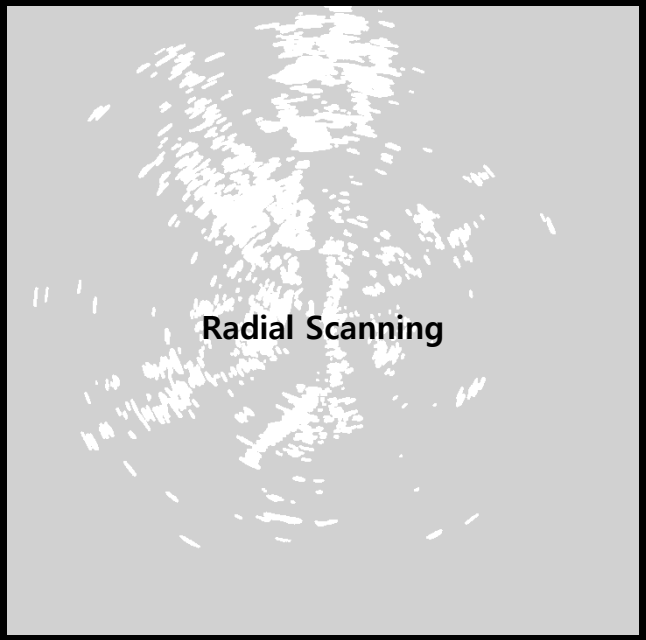
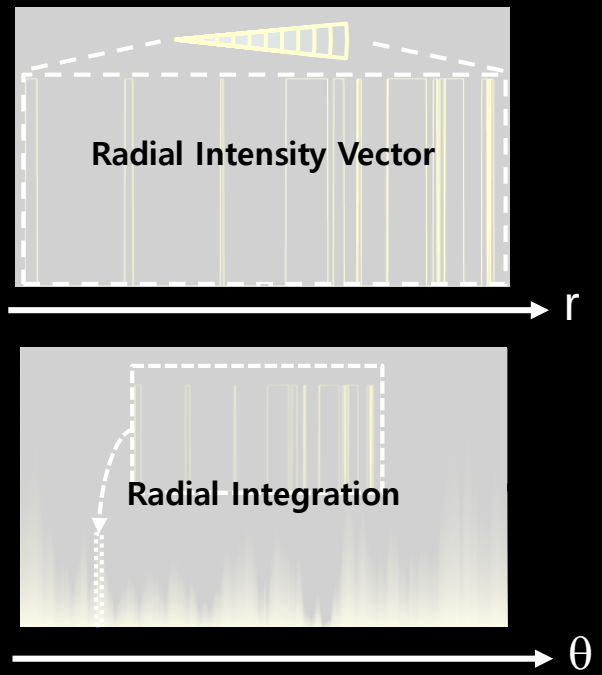
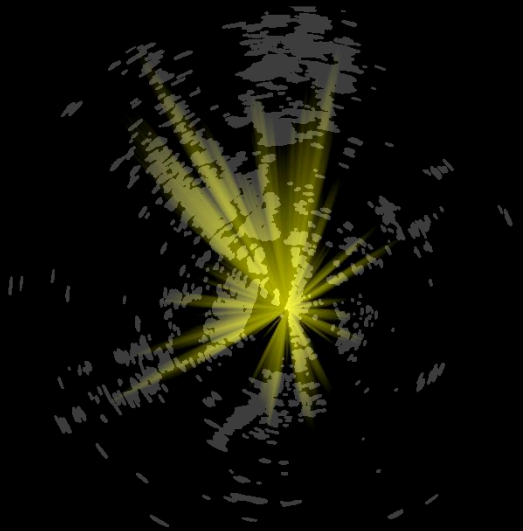
LodeStar Descriptor







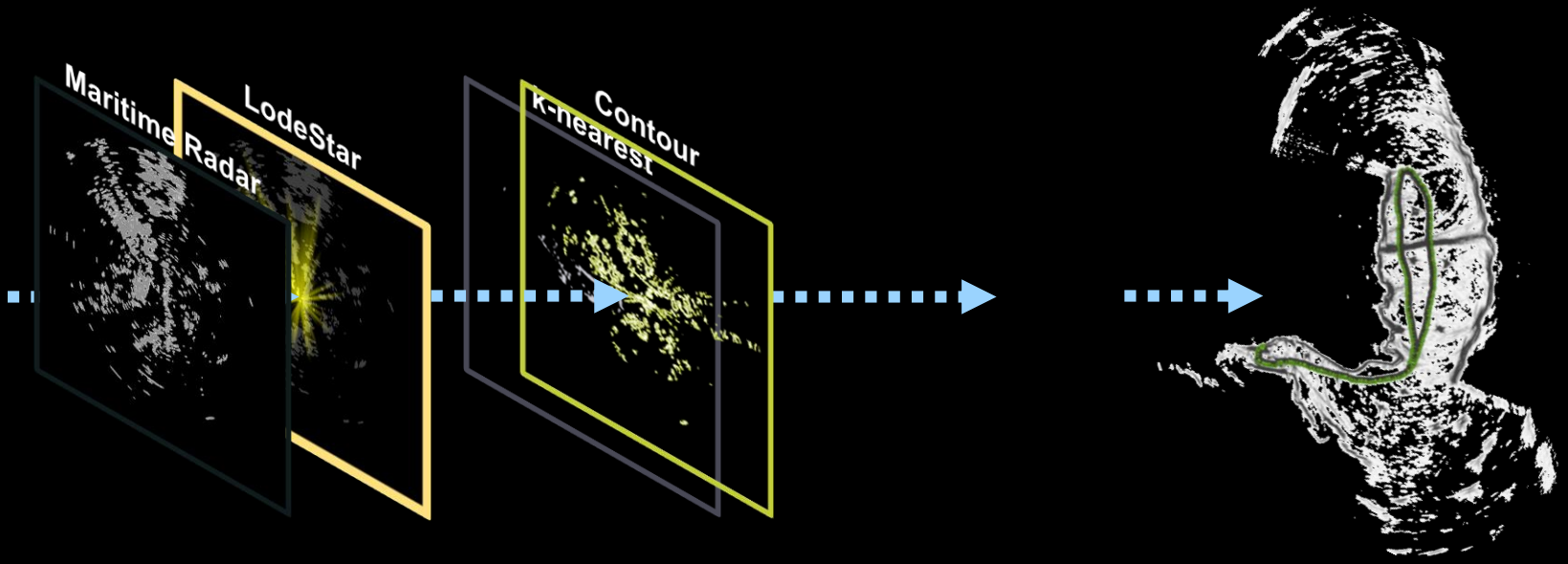


LodeStar Descriptor (Rotation Estimator)

Hyesu Jang, Minwoo Jung, Myung-Hwan Jeon, Ayoung Kim "LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry." IEEE RAL 2024.

Radar Odometry using LodeStar





Rotation by LodeStar

Contour from pointcloud

Hyesu Jang, Minwoo Jung, Myung-Hwan Jeon, Ayoung Kim "LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry." IEEE RAL 2024.

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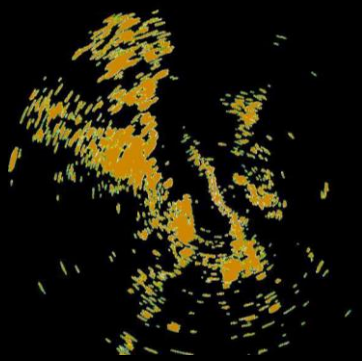
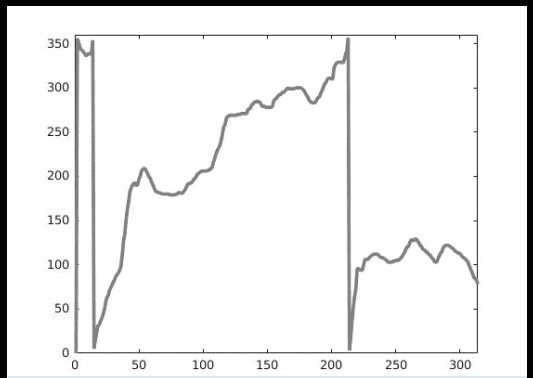
Radar Odometry using LodeStar



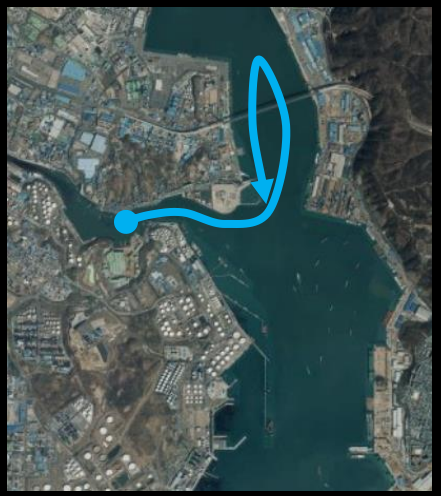


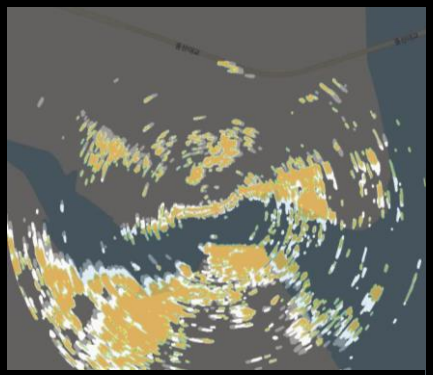
Original Radar

LodeStar

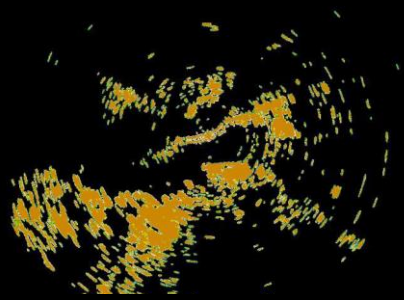


Final Estimated Rotation

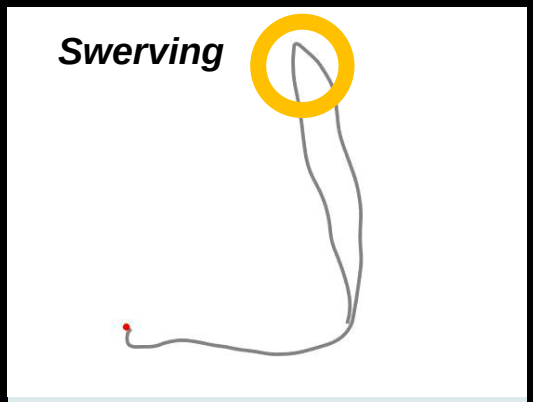




Ground Truth



Initial Estimation



Final Estimated Odometry

Groundtruth
k-nearest
Proposed

19 Hyesu Jang, Minwoo Jung, Myung-Hwan Jeon, Ayoung Kim "LodeStar: Maritime Radar Descriptor for Semi-Direct Radar Odometry." IEEE RAL 2024.

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Radar SLAM

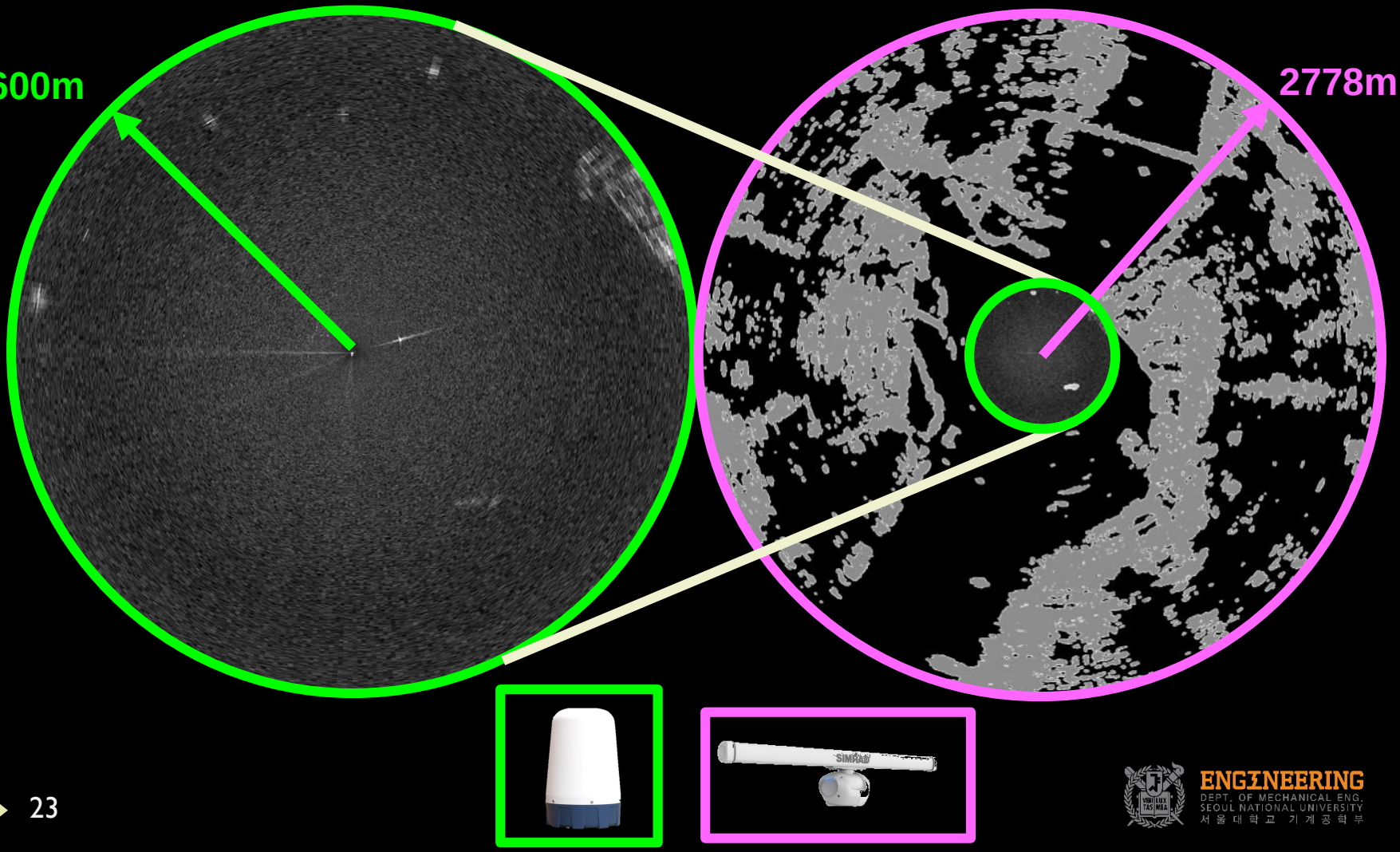
Maritime SLAM and Radar Fusion

Maritime SLAM and Radar Fusion

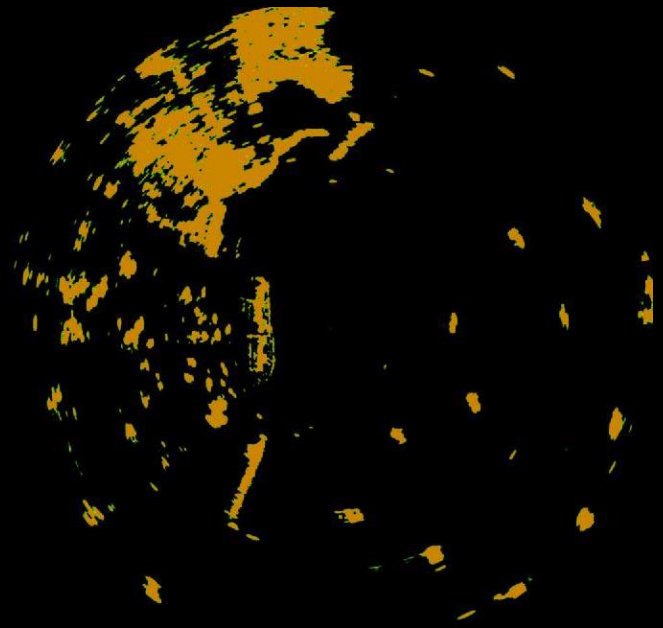
Narrow Canal

Wide Canal

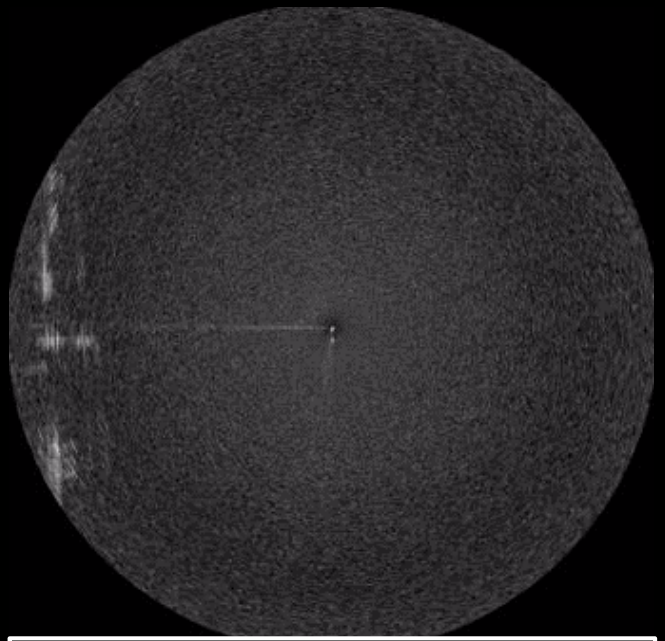
Maritime SLAM and Radar Fusion



Maritime SLAM and Radar Fusion

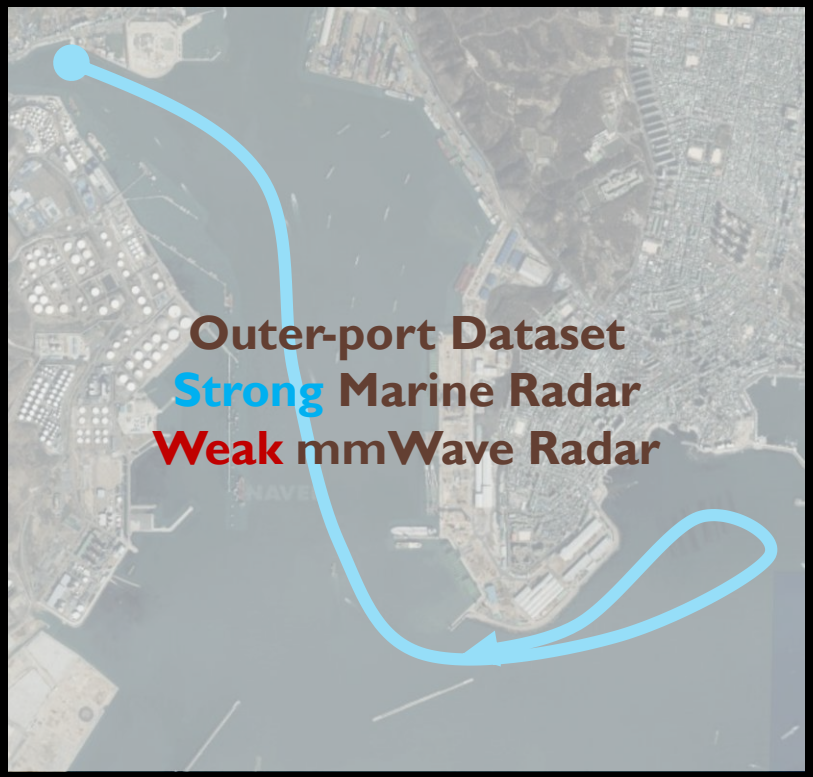


Marine Radar

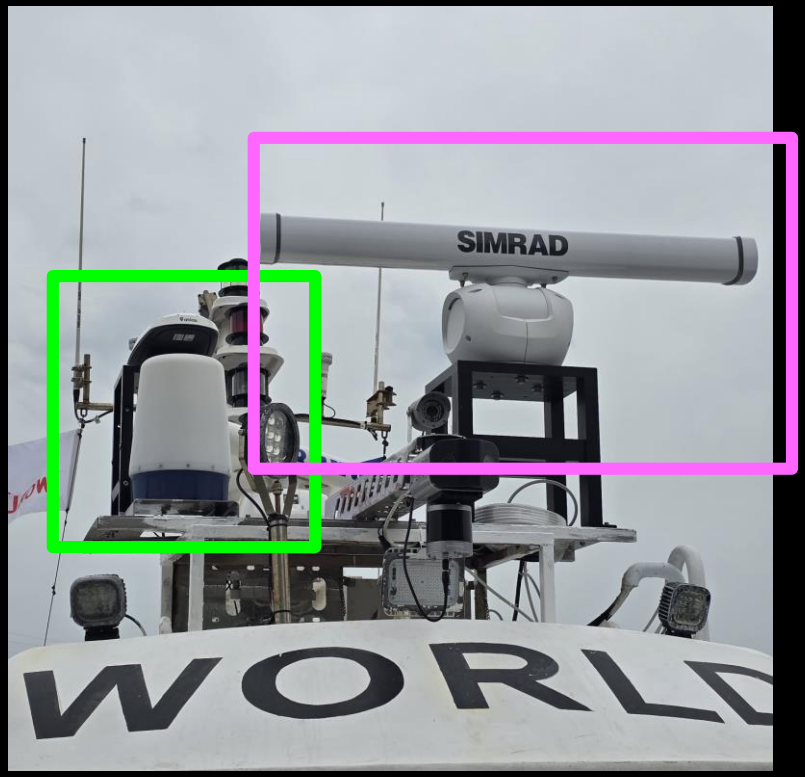


mmWave Radar

Maritime SLAM Validation



Maritime SLAM Validation

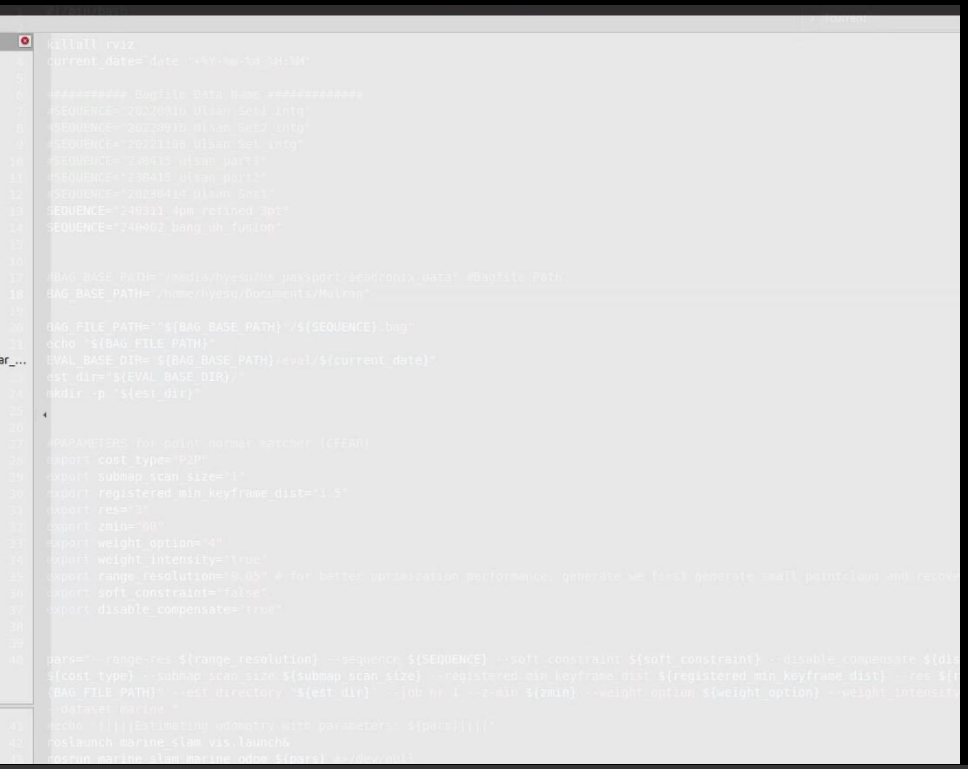


Maritime SLAM Validation

SLAM (mmWave only) near port

High noise for marine radar near shore
→ only mmWave radar

Maritime SLAM Validation



Odometry w/ Marine radar

+ PR w/ mmWave = SLAM

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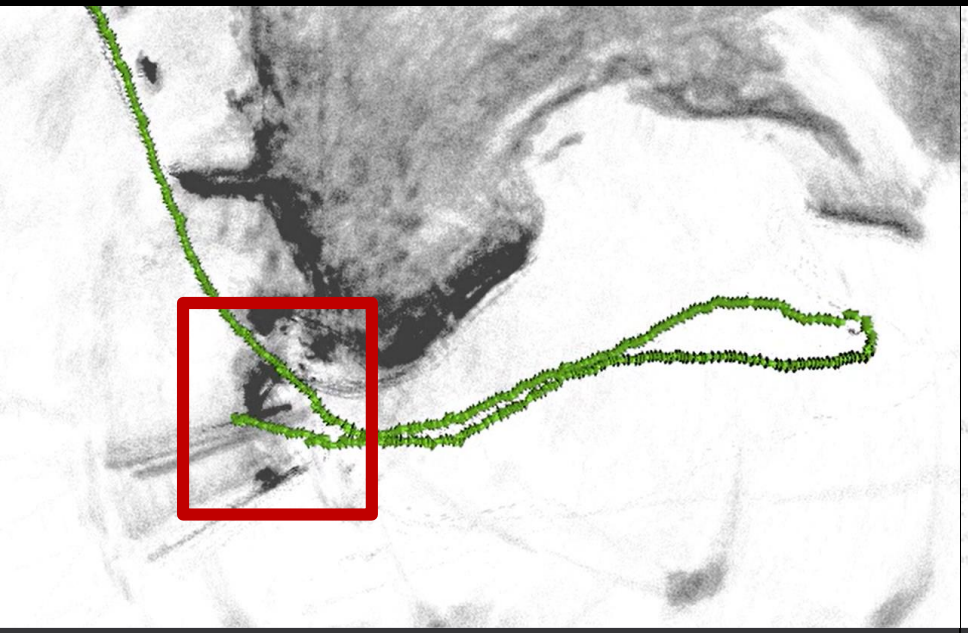
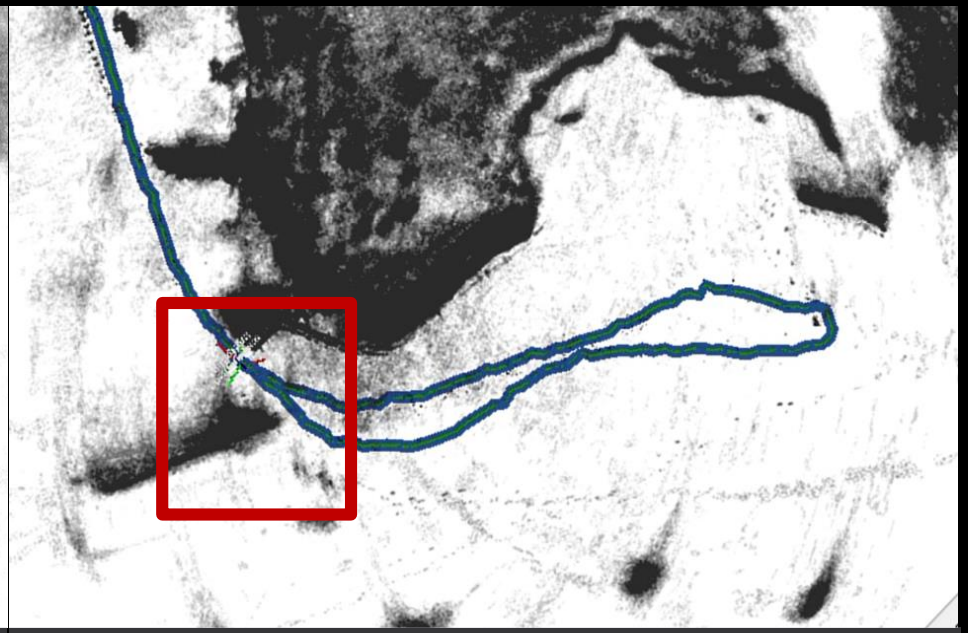
Maritime SLAM Validation



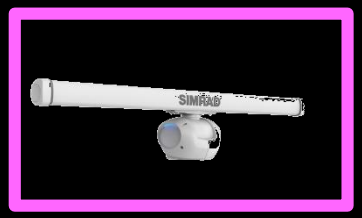
Odometry



SLAM

Concluding Remarks

- Marine unmanned surface vehicle
  - mmWave + xband radar combination



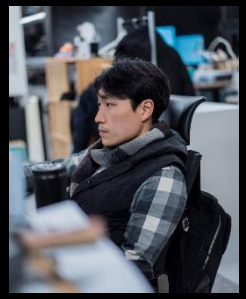
  - Promising multi-modality for marine unmanned surface vehicle

Acknowledgement

- This work was supported by

SEADRONIX


Hanguen Kim Ph.D.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Thank you very much !!

RPM Robotics Lab @SNU

Visit https://rpm.snu.ac.kr for papers, codes and videos!