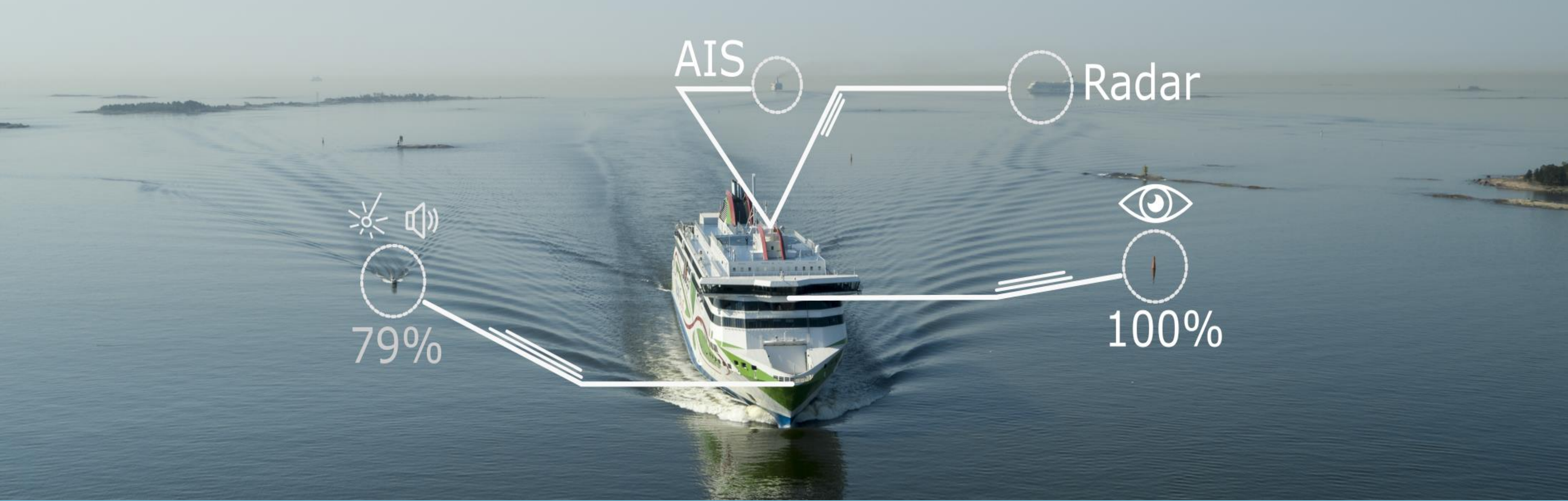

ARTIFICIAL INTELLIGENCE / MACHINE LEARNING SENSOR FUSION FOR AUTONOMOUS VESSEL NAVIGATION (NAVISP-EL1-020 MARITIME AI-NAV)

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

NAVISP industry days
16.6.2022 Tuomo Malkamäki

AIMS & MOTIVATION

“to develop solutions for safety and efficiency in maritime navigation utilizing new and existing ship sensors and fusing this data using artificial intelligence (AI) algorithms and techniques”

Motivated by

- *the need for autonomous decision-making related to maritime navigation*
- *the integrity monitoring of the sensor system itself*

Main objective is to develop and evaluate state-of-the-art solutions for positioning and detection of objects in maritime environment

$\Rightarrow$ *Robust situational awareness*

PARTICIPANTS

SCOPE

⇒ Project focuses on sensing, positioning & situational awareness

- No autonomous operation just yet

- Sensors within the scope: GNSS, visual cameras, microphones, LiDAR*. Vessel data such as GNSS, RADAR*, weather information, and AIS.
- Out of scope: real-time operation, continuous operation, other sensors on-board the vessel, automatizing other functions of the vessel

- Sensor R&D
- Test setup
- Data preprocess

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- AI & ML
- Data processing

A!
Aalto University

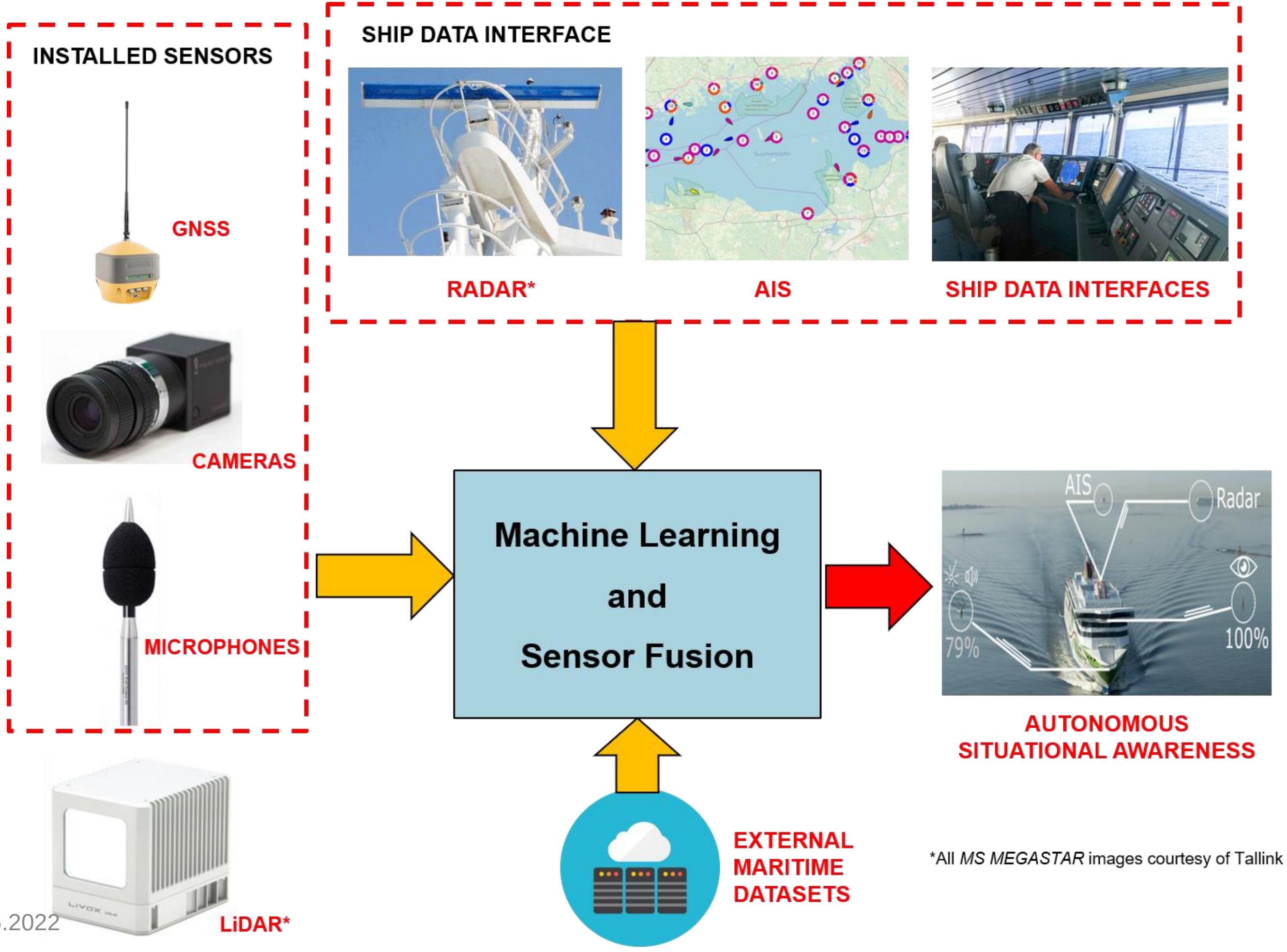
- Maritime requirements
- Ship system integration
- Test vessel

Fleetrange

In kind, subcontract:

- Tallink Megastar
  Valmet, Wärtsilä

⇒ Validation and access from ship-systems



*All *MS MEGASTAR* images courtesy of Tallink

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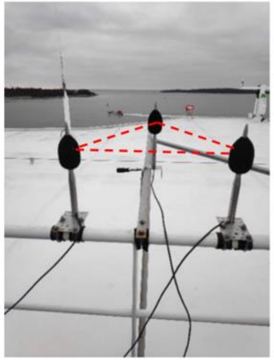
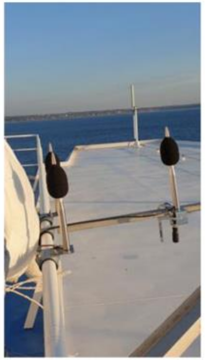
*All *MS MEGASTAR* images courtesy of Tallink

SENSOR PLACEMENT

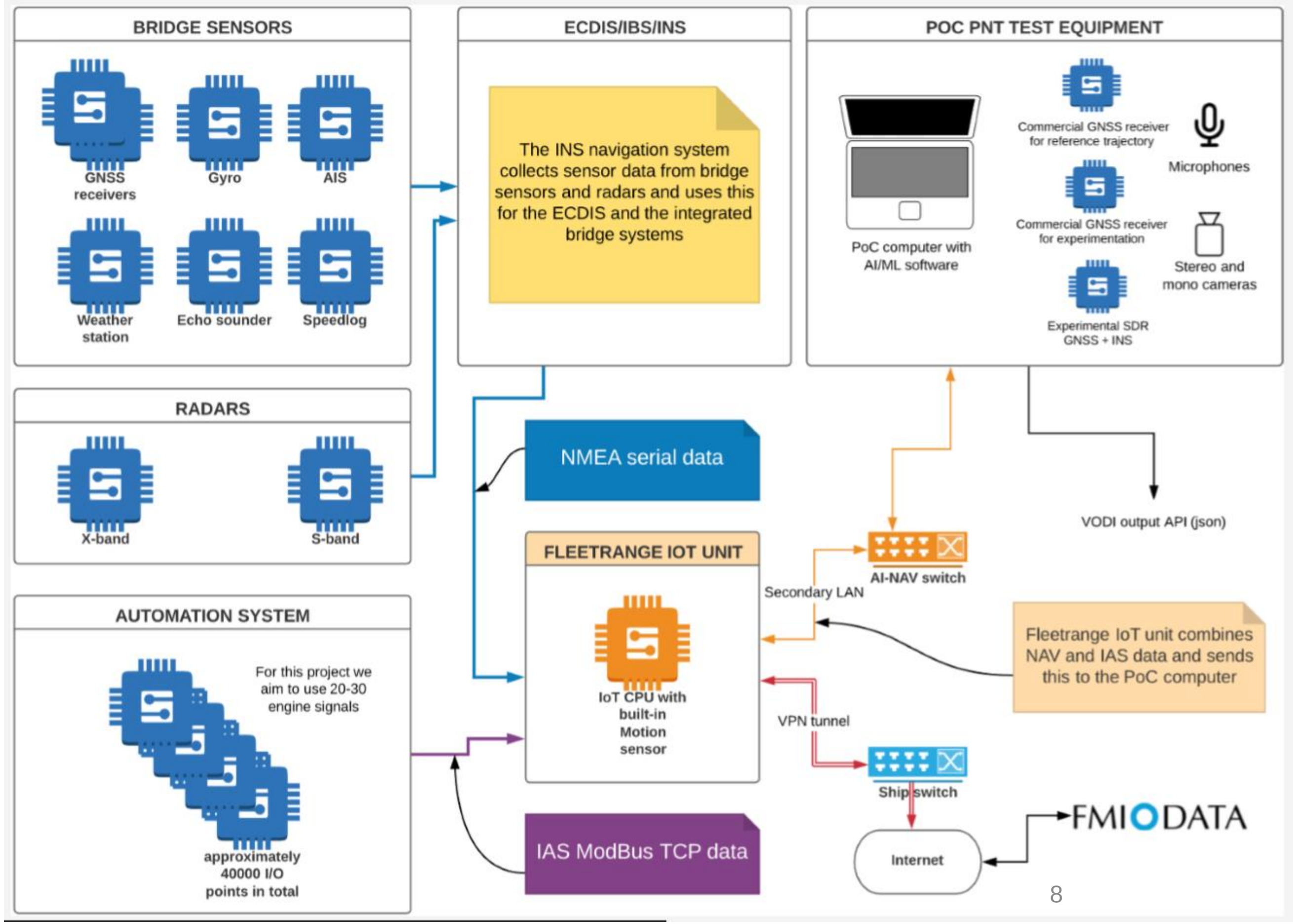






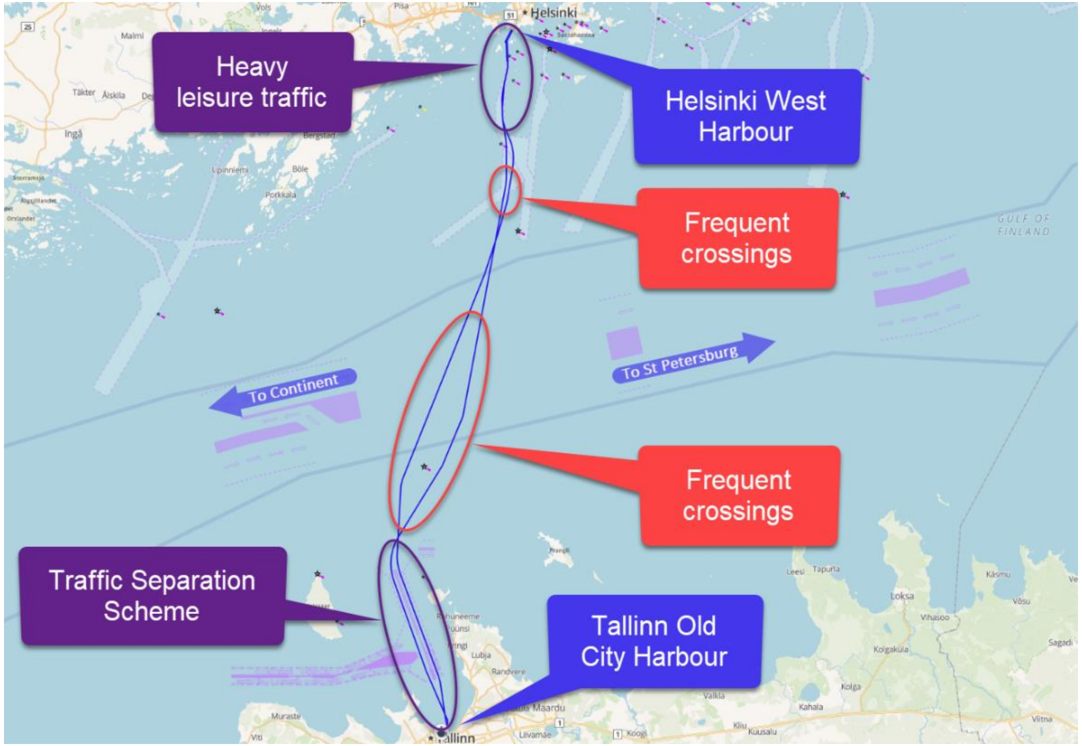
SETUP SHIP IF



*ECDIS = electronic chart display and information system
*IBS = integrated bridge system
*AIS = automatic identification system

TEST, VALIDATION CAMPAIGN

- Several field campaigns for data collection on Megastar
  - Lots of data
- Winter conditions were tricky
- Nice variety of traffic, Nav-aids, harbor structures & shoreline



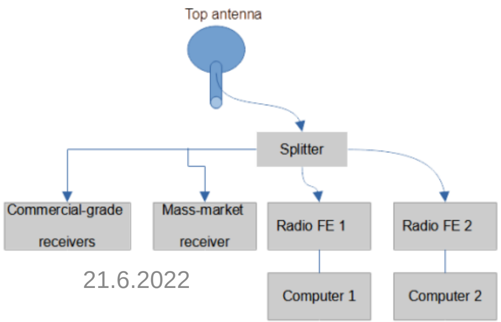
GNSS POSITIONING

- Required for other sensors' analysis
- Novatel + RTK for precise reference
- Topcon and u-blox for longer data analysis
- Recorded raw data processed with SW
  - FGI-GSRx (in-house) Matlab receiver (post-processing)
  - GNSS-SDR C++ receiver (real-time like mode)
  - RTK-Lib for EDAS operation

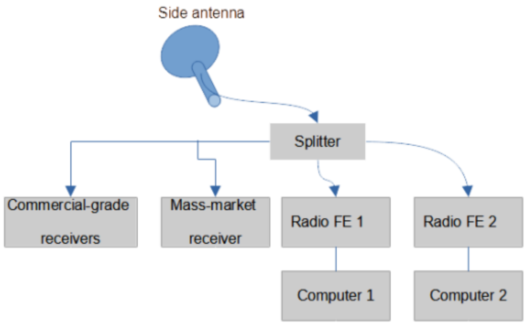
Results:

- ~10 cm reference accuracy with RTK
- Better than 3 m accuracy with multi-constellation multi-frequency GNSS (including Galileo and EGNOS)

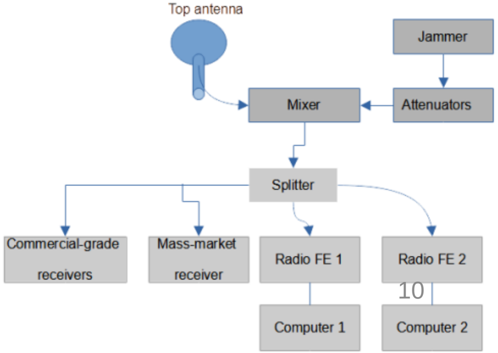
Nominal Scenario



Multipath, Fading Scenario



Interference Scenario



GNSS POSITIONING

- Nominal static acc. Using FGI-GSRx SDR

	Galileo E5a	Galileo E1 + E5a	GPS L5 + Galileo E5a	GPS + Galileo L1/E1+L5/E5a
95% Horizontal Accuracy (m)	1.72	2.35	1.24	2.65
95% Vertical accuracy (m)	2.28	3.84	1.64	3.80
No. of satellites in position solution	7	7	7 Galileo + 3 GPS	7 Galileo + 7 GPS (3xL5)
Duration of trajectory (s)	150	150	150	150
Receiver used	FGI-GSRx SDR	FGI-GSRx SDR	FGI-GSRx SDR	FGI-GSRx SDR

- Commercial rx perf.

	Topcon HiPER HR Galileo+GPS Dual-Frequency	ublox GNSS + SBAS
95% Horizontal Accuracy (m)	2.06	1.99
95% Vertical accuracy (m)	2.17	4.73
Avg. Speed Error (km/hr)	0.047	0.060
Avg. # of satellites in position solution	18	28
Duration of trajectory (minutes)	211	128

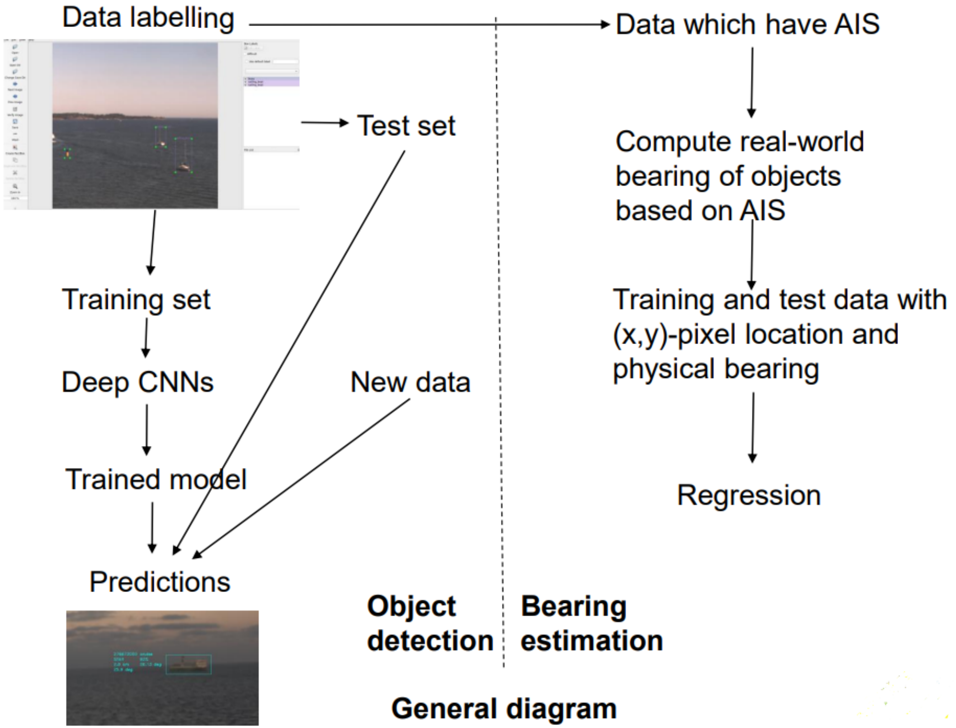
- Average error in ranging to the detected target AIS

	GNSS without impairments	Satellite masking/multipath	Low-power jamming
Average error in ranging	5.73 m	9.67 m	8.02 m
Number of time epochs used for averaging	973	1645	4142

CAMERAS

Mono and stereo camera sets

- Post processing
- Object detection and bearing estimation, stereo for distance estimation
- SSD, YOLO methods to extract ships, buoys
- Several existing labeled sets used for training
  - AIS for verification, target acquisition



General diagram

CAMERAS

- SSD is much faster (maybe due to implementation)
- YOLO is significantly better on detecting small targets
- Training GPU intensive, prediction is lightweight
- SSD&YOLO verifiable using numerical experiments

Two buoys are detected by the camera at short-range. MS Finlandia is detected with Camera and AIS. The estimated bearing (-32.88º) from camera is very close to true bearing (-33.3º) from AIS.

CAMERAS

- Bearing estimation:
  - error less than 2 deg by using only six samples (ref AIS & GNSS)
- Distance est. (stereo cam)
  - error grows as a function of distance, good up to ~1km

Target Name	Distance (GNSS and AIS) (km)	Distance (stereo vision) (km)	Difference (m)
Finlandia	0.9877	1.0249	37.20
Star	1.078	1.042	36.00
Star	1.3018	1.06253	239.27
Rocamar	6.565	5.6214	943.60

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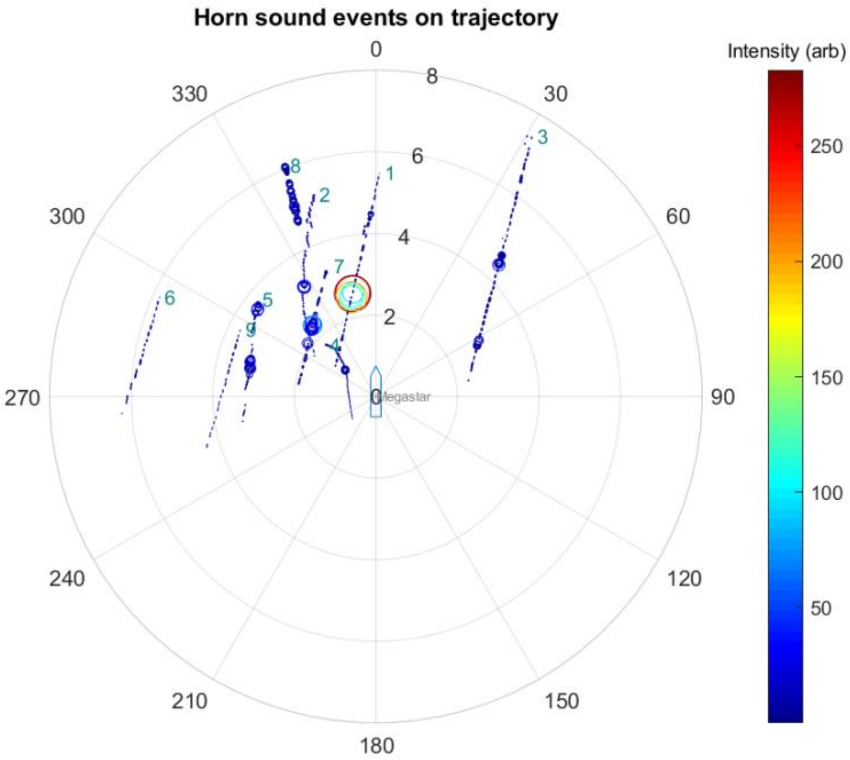
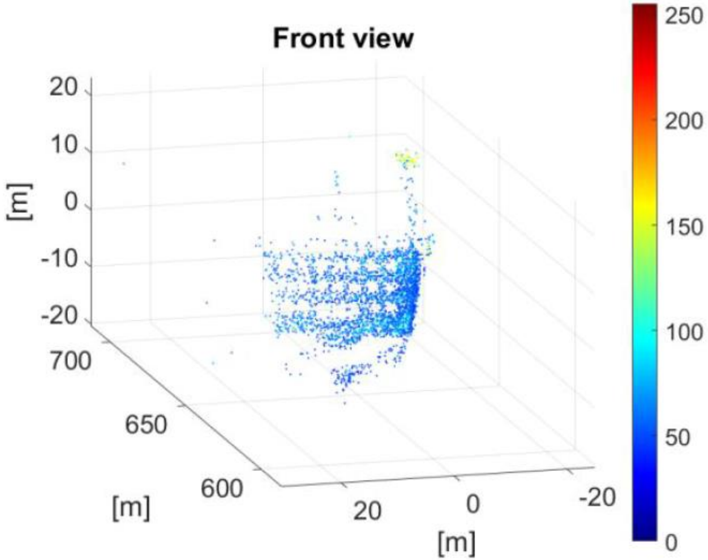
SOUND

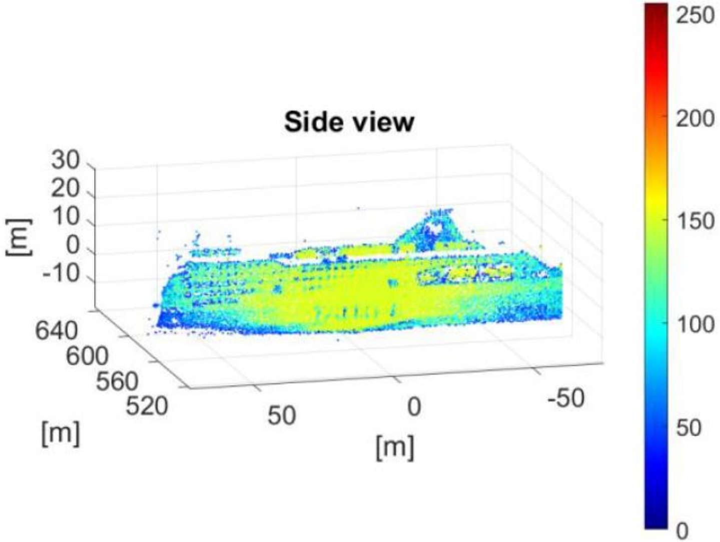
- Equilateral arrangement of microphones
  - Side length = 0.5 m
- Horn sounds and AIS data captured
- Typical horn sound frequency:
  - MS STAR ~134 Hz
  - MS FINLANDIA ~170 Hz
  - Audio sampled at 50 kHz
- Noise filtering, energy based event detection based on Hilbert-transform
- Best estimate of RMS error is 6.94 deg, while overall RMS error is 20.1 deg
  - Few events not detected



LIDARS

- Feasibility study
    - Augment cameras in dark, night, fog conditions
- Range, angular resolution and pulse rate issues





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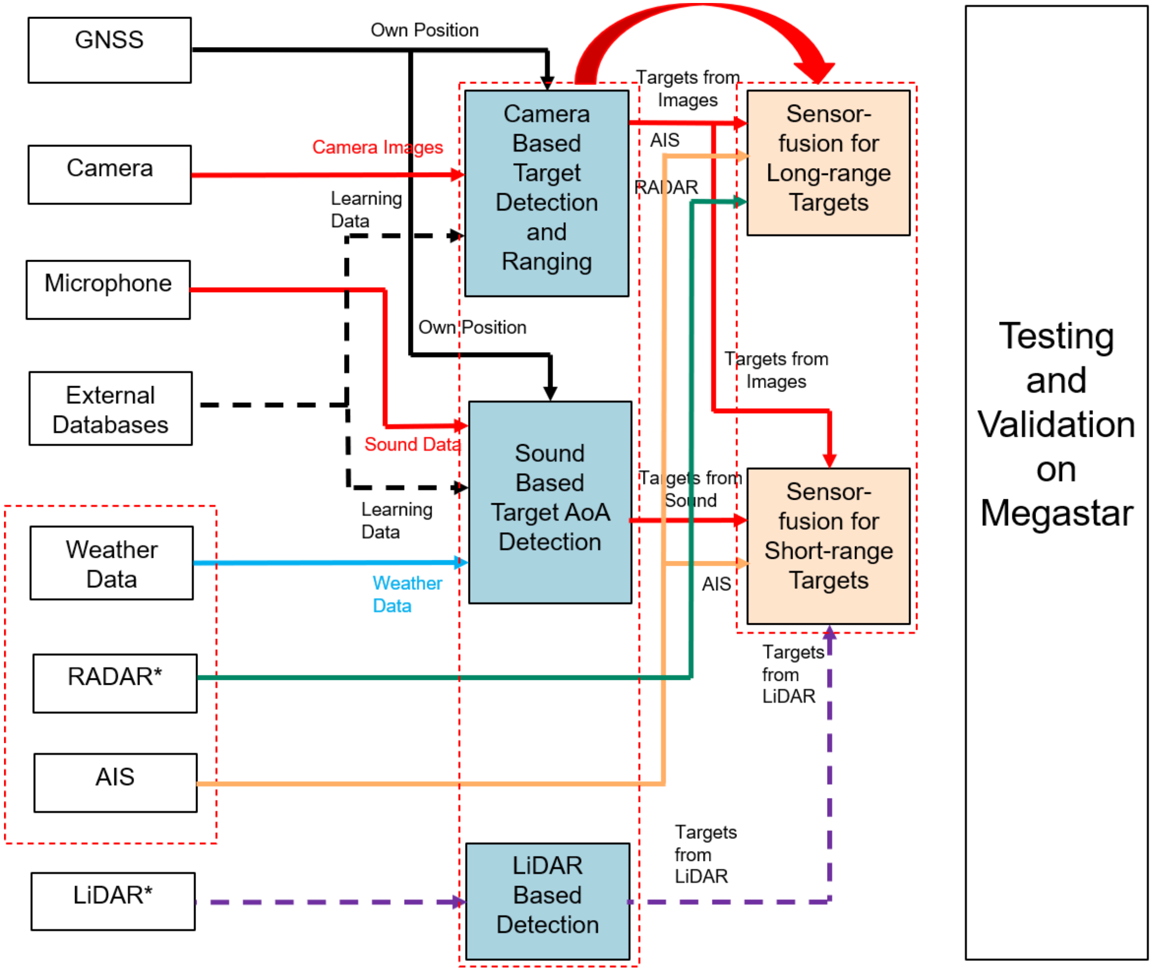
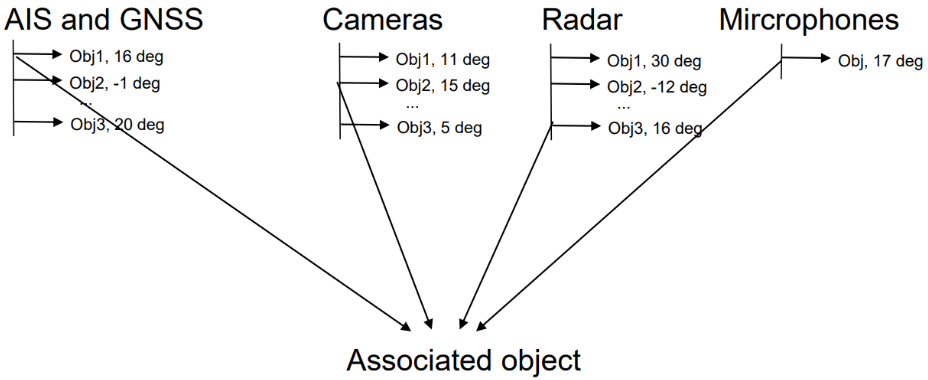
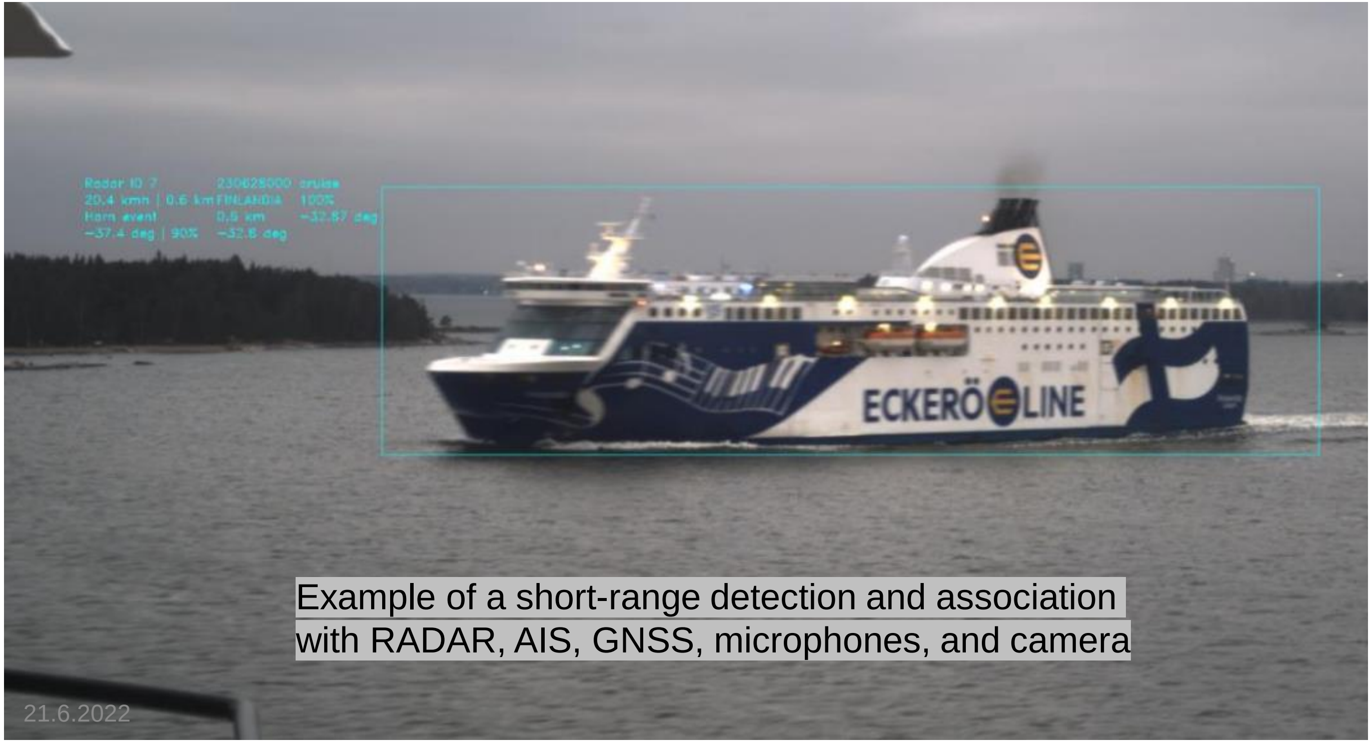

GNSS
Own Position
Camera
Camera Images
Learning Data
Microphone
External Databases
Camera Based Target Detection and Ranging
Own Position
Sound Data
Learning Data
Sound Based Target AoA Detection
Weather Data
Weather Data
RADAR*
AIS
LiDAR*
LiDAR Based Detection
Targets from Images
AIS
RADAR
Sensor-fusion for Long-range Targets
Targets from Images
Targets from Sound
Sensor-fusion for Short-range Targets
AIS
Targets from LiDAR
Targets from LiDAR
Testing and Validation on Megastar

SENSOR FUSION, DATA ASSOCIATION

- Sensors produce noisy target location, bearing, class
- Using probability distributions for sensors and target AIS/RADAR data, nearest neighbor data association algorithms can be applied
  - Checking for high probability areas, i.e. gating
- Bayesian filtering and smoothing methods can be used for trajectory and intent prediction
  - (For a given associated object)



DATA ASSOCIATION



Example of a short-range detection and association with RADAR, AIS, GNSS, microphones, and camera

CONCLUSIONS

- General challenges
  - Amount of data
  - Ship size impacts a lot of things
  - Capturing enough variety (weather / season)
    - Varying weather conditions have huge impact
  - Sensors
    - Unoptimal choices, calibration & synchronization
    - Installation
    - Robustness

CONCLUSIONS…

Challenges for sensor fusion

- Varying sensor ranges
  - More overlap required

Challenges for AI

- (Training) data is very imbalanced
- Difficult to get valuable training data in wintertime, long range
- Data labelling by professional companies?
  - No proper training data available for long range camera detection
  - Target GNSS+AIS very useful for automated training data collection

CONCLUSIONS

- Despite challenges, good results
  - Methods, sensors can be scaled
- GNSS good for navigation, but not yet for autonomous docking
- Lidars developing fast, easy to add, good for docking
  - mmWave radars as well?
- AI very robust with decent training data
  - Land etc detection easy relative to ships, buoys
  - Typically high detection rates & accuracy
- Sensor fusion relatively straightforward if errors known
  - AI methods provide good error/confidence estimates

MORE INFORMATION

Please contact tuomo.malkamaki@nls.fi for further question

Please see also

https://navisp.esa.int/project/details/51/show

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Please contact me for further questions!

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Thank you!

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