FIG WORKING WEEK 2023
28 May - 1 June 2023 Orlando Florida USA
Protecting Our World, Conquering New Frontiers

Senses for Submarines

Concepts for Optical- and Acoustic-Based Odometry and SLAM for Underwater Navigation

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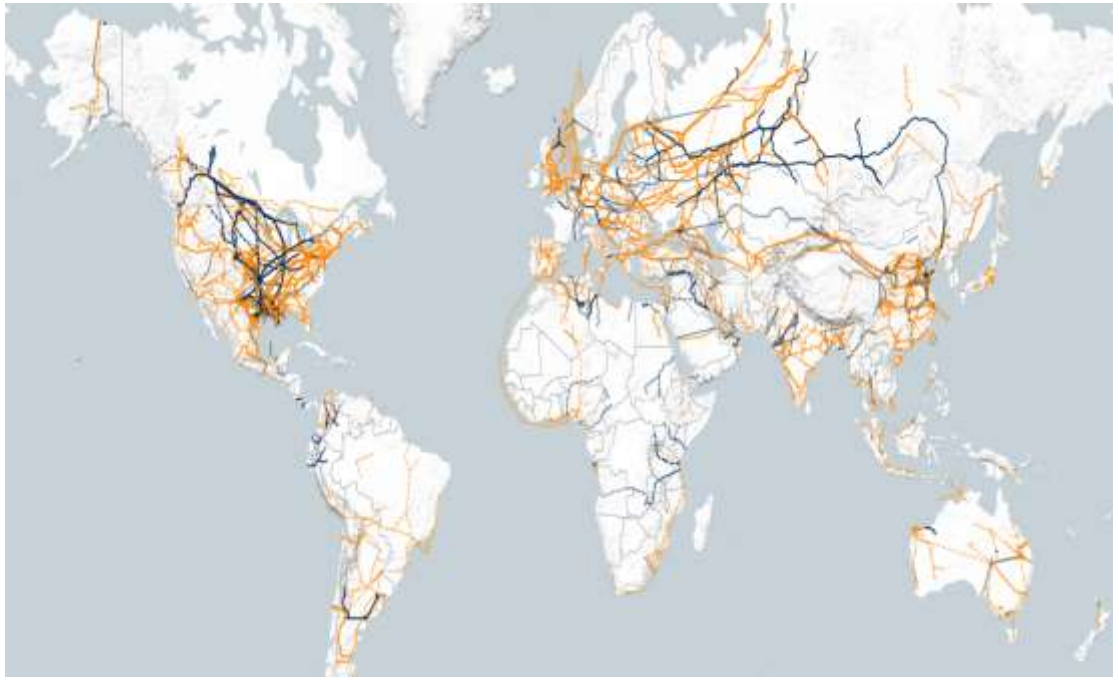
Gliederung

- Introduction
- Challenge and general idea
- Conceptual approach
- Outlook

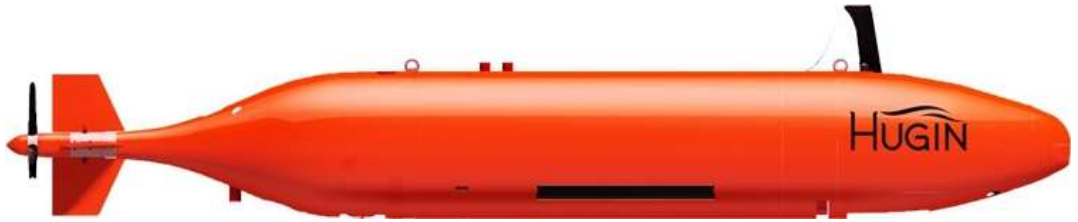
Introduction



Source: Tagesspiegel

- Pipelines and deepseacables connecting countries and continents
- Hazards:
  - Human activities (un-/intentional)
  - Natural causes
  - Ageing
- Regular Monitoring

Multi-sensor system: The AUV



Source: Kongsberg

Autonomous underwater vehicles determined for monitoring

- Shallow water or deepsea
- UXO detection and defense
- Environmental monitoring
- Critical infrastructure (e. g. pipelines)

Source: L3Harris

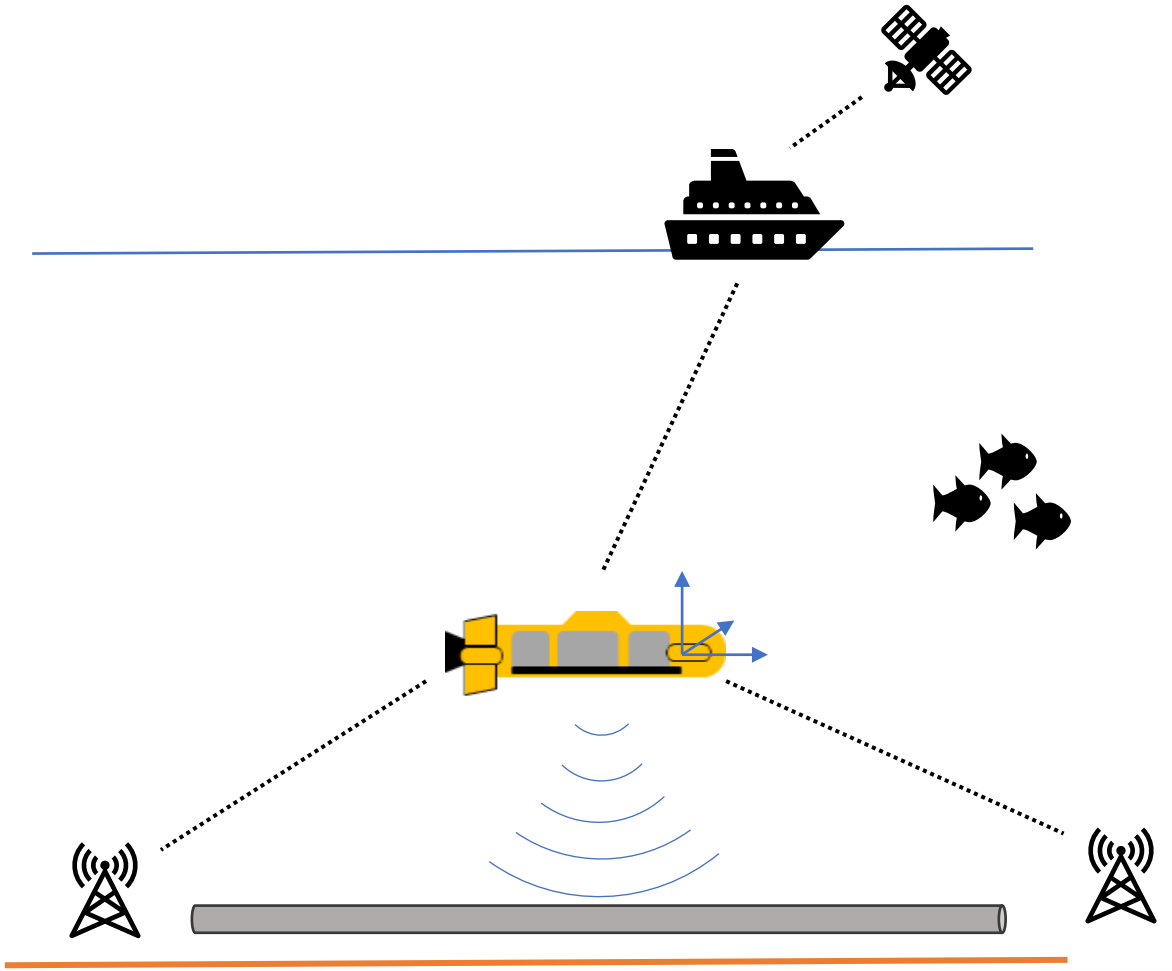
Commercial available AUVs

Challenge of navigation underwater

- Necessity
  - Safe maneuverability of the AUV
  - Georeferenced location of the recorded sensor data
- Communication
  - Underwater radio does not work
  - Intervention on the system only possible to a limited extent
- Economic viability
  - Specific sensor technology
  - Expensive deployment of assisting devices

State-of-the-art: Navigation

- Dead Reckoning
  - FOG/RLG-IMUs
  - Doppler velocity logger
  - Accuracy: 0.04 to 2.0 %
- Enriched with
  - USBL from mobile systems
  - LBL from stationary beacons



CIAM

"Cooperative Development of a Comprehensive Integrated Autonomous Underwater Monitoring Solution"

Overall Goal:

Development of AUV for autonomous tracking of pipelines up to 500 km in 6.000 m depth

Duration: 2021 to 2024

Funded by: Bundesministerium für Wirtschaft und Technologie

Consortium: ROSEN empowered by technology, GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Innomar, DFKI, HafenCity Universität Hamburg, TU berlin, Universitätsklinikum Freiburg, baltic FuelCells GmbH, FORMLEO

Goal of Project

Concept

- Port-to-port-solution
- Reduction of costs
- Using the opportunities of collected sensor data

Part of HCU

- MEMS instead of FOG
- Reduction of LBL und USBL Updates → **Reduction of costs**
- Renunciation of mothership

CIAM-Prototype of AUV

AUV-Design: Sensors for Surveys

Multibeam echosounder: Geometrical referenced scan line below

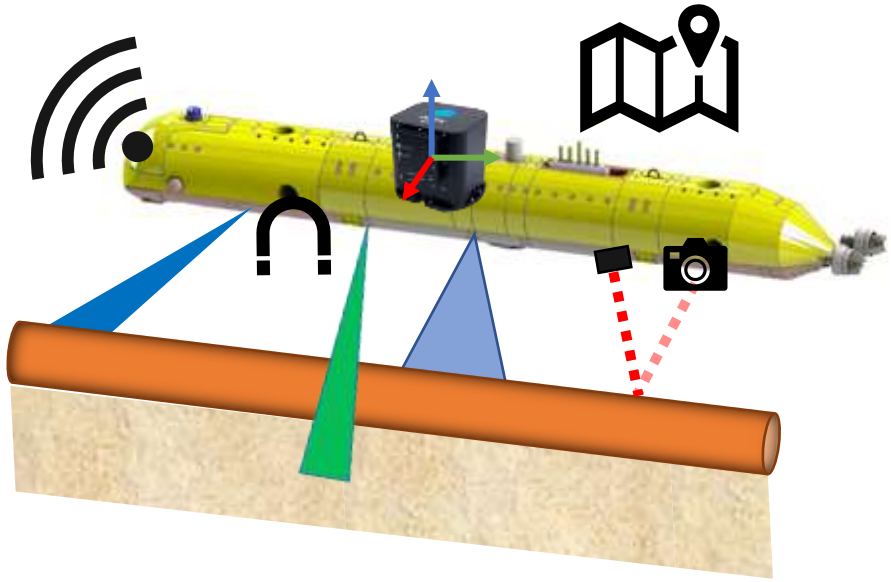
Forward looking sonar: 2D image ahead of AUV

Subbottom profiler: Singlebeam signal through sediment

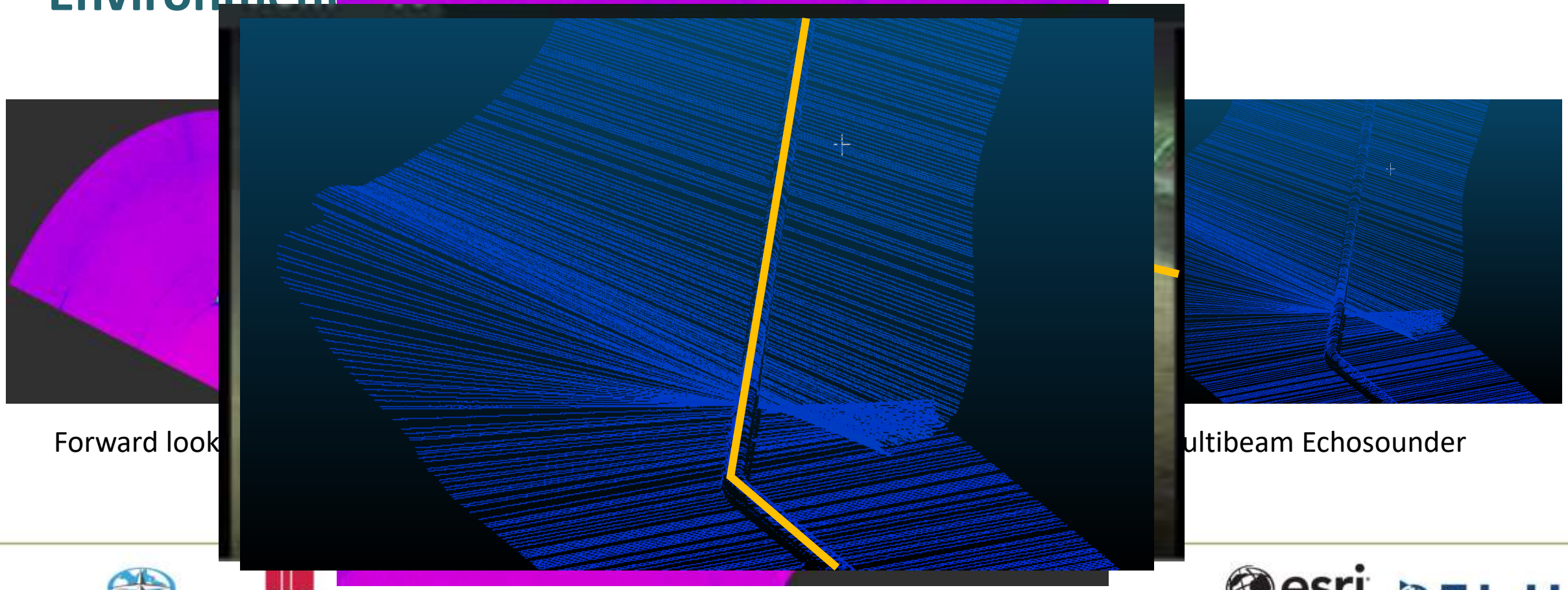
Electromagnetic sensitiv sensor: Changes of magnetic field

Laserline scanner: Geometrical referenced scanned line below

Camera: Images

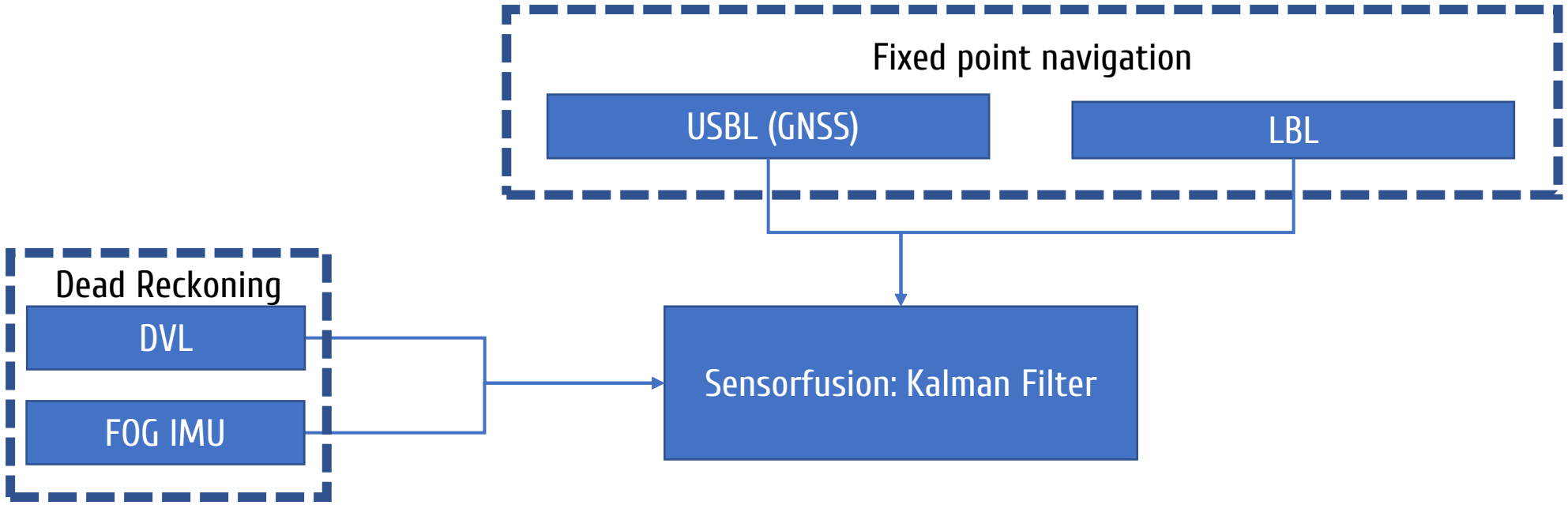


Environmental representation

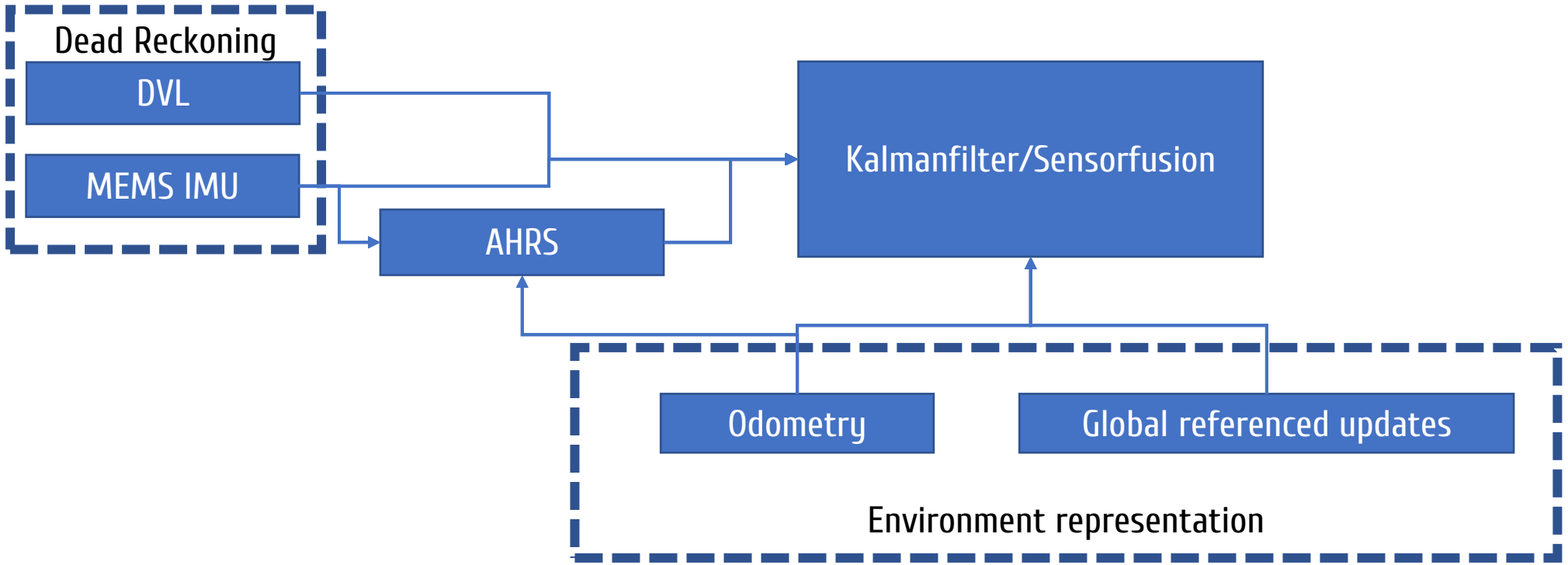


Forward look ultibeam Echosounder

Conventional Filter



Alternative Concept for Navigation



Heading: ANN-based

- Idea: Fusion of magnetometer and gyro considering their error sources
- Complementary filter

$$\psi = \psi_{mag} * \alpha + \psi_{gyr} * (1 - \alpha) \qquad \text{with } \alpha = 1$$

- ANN-model trained with RLG predicting controlparameter α based on magnetometer and gyro

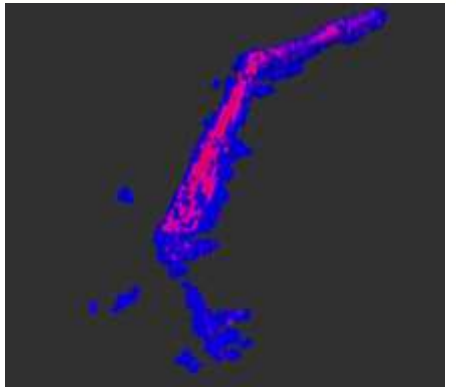
MEMS- and RLG-IMU

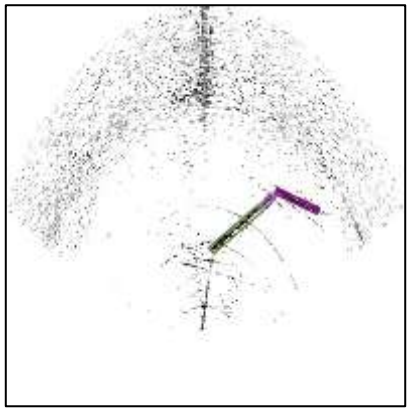
Heading: Visual Odometry (1)

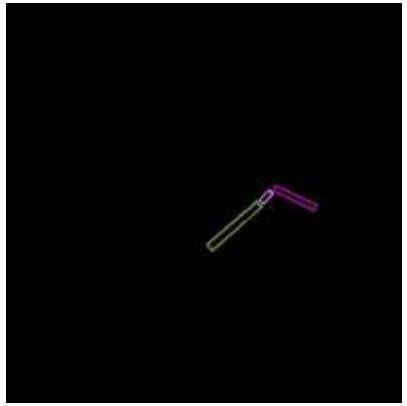
- Idea: Control sensor fusion with information about change of pipeline orientation
- Complementary filter
  - Adding layer to ANN to consider complexity

$$\psi = \psi_{mag} * \alpha + \psi_{gyr} * (1 - \alpha) \qquad \text{with } \alpha = 1$$

- ANN-model trained with RLG/FOG predicting controlparameter α based on relative orientation of pipeline







Detected Pipeline

Heading: Visual Odometry (2)

- Idea: Derive the orientation of AUV by estimation of pipeline orientation
- Based on Forward looking sonar

$$\psi = \psi_{mag} * \alpha + \psi_{gyr} * \beta + \psi_{pipe} * \gamma \qquad \text{with } \alpha + \beta + \gamma = 1$$

- Heading ψ_{Pipe} obtained by integration or a-priori-information
- ANN-model trained with RLG/FOG predicting controlparameter α, β and γ based on relative or absolute orientation of pipeline

Traveled Distance: Visual Odometry

- Idea: Compare conintuous features with traveled time like
  - Numbering
  - Joints
  - Flanges
  - Electromagnetic changes
- Receiving an absolute traveled distance
- Fed directly into sensor fusion

Source: Reuters

Numbering on pipeline

Global referenced position: A-Priori-knowledge

- Idea: Replace USBL and LBL with unique features
  - Patches
  - Numbers
  - Terrain features
  - Turns and bends of the pipeline
- Mapping
  - Prior surveys with the AUV or other survey systems
  - Specifically build in features
  - Knowledge through relocation of the pipelines
- Fed into sensorfusion

Source: NatureNews

Unique features on pipeline

Local position: SLAM

- Idea: Increase accuracy and robustness with loop-closure
- Enabling detailed mapping of Points-of-Interests or docking process
- Benefits for repair teams
- Implementation in mission planning needed

Challenges of Environment-based Navigation

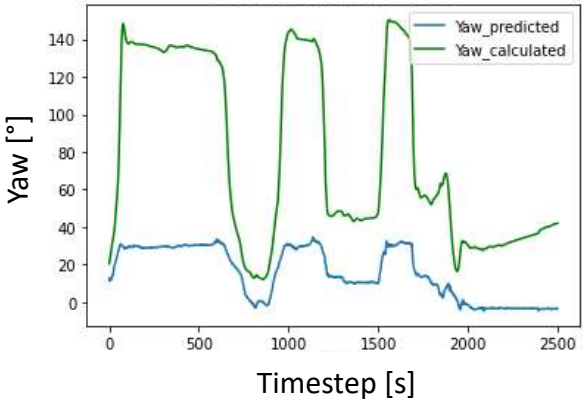
- Semantic environment representation is a challenging field
- Features changes of the years
  - Biofouling
  - Underwater landslides and sedimentation
  - Monotonous bottom or pipeline
- Realtime capacity of processing unit
- Differences in various sensors

Outlook for the project until 2024

- Major challenges
  - Sensitiv data of critical infrastructure
  - Expensive fieldtests
- Testing concepts and ideas in simulation
- Collecting (substitute-)data with extra AUV
- Training and validating of ANN-models

Source: IQUA Robotics

SPAROS AUV for Shallow Waters



CIAM-Prototype of AUV

Thank you for your attention!

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Questions and feedback are welcome!