MODERN SYSTEMS OF UNDERWATER NAVIGATION AND CONTROL ARCHITECTURE FOR AUTONOMOUS CARGO SUBMERSIBLES

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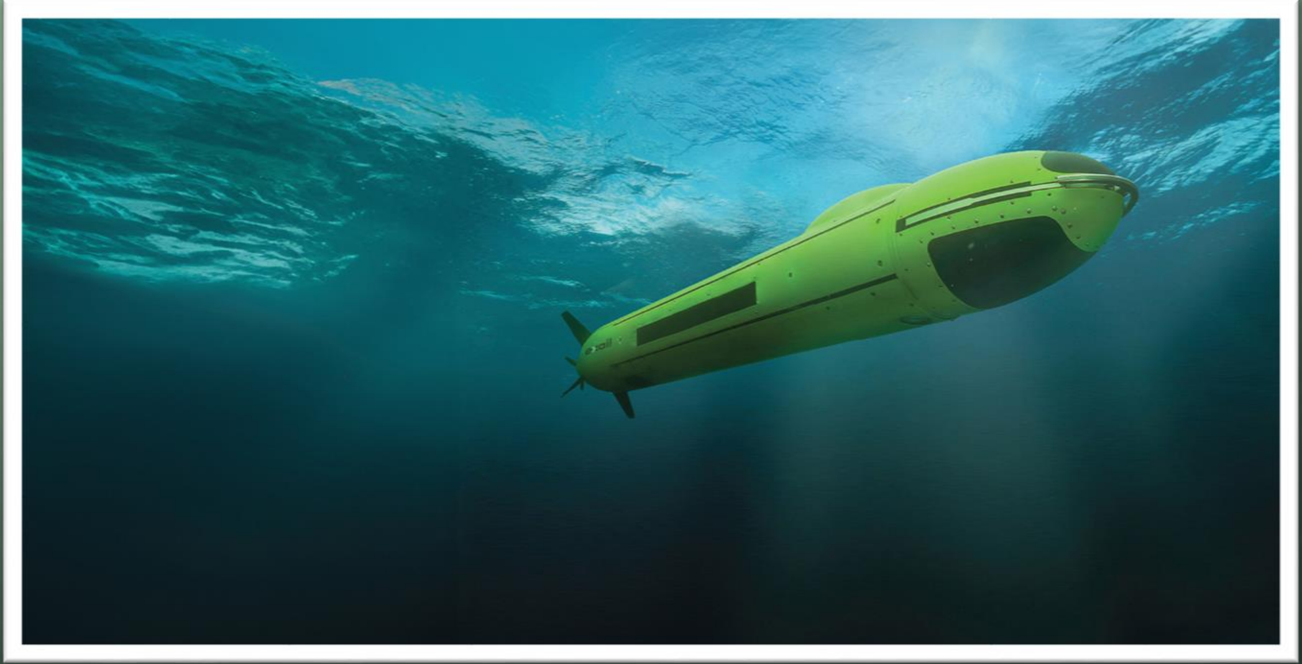
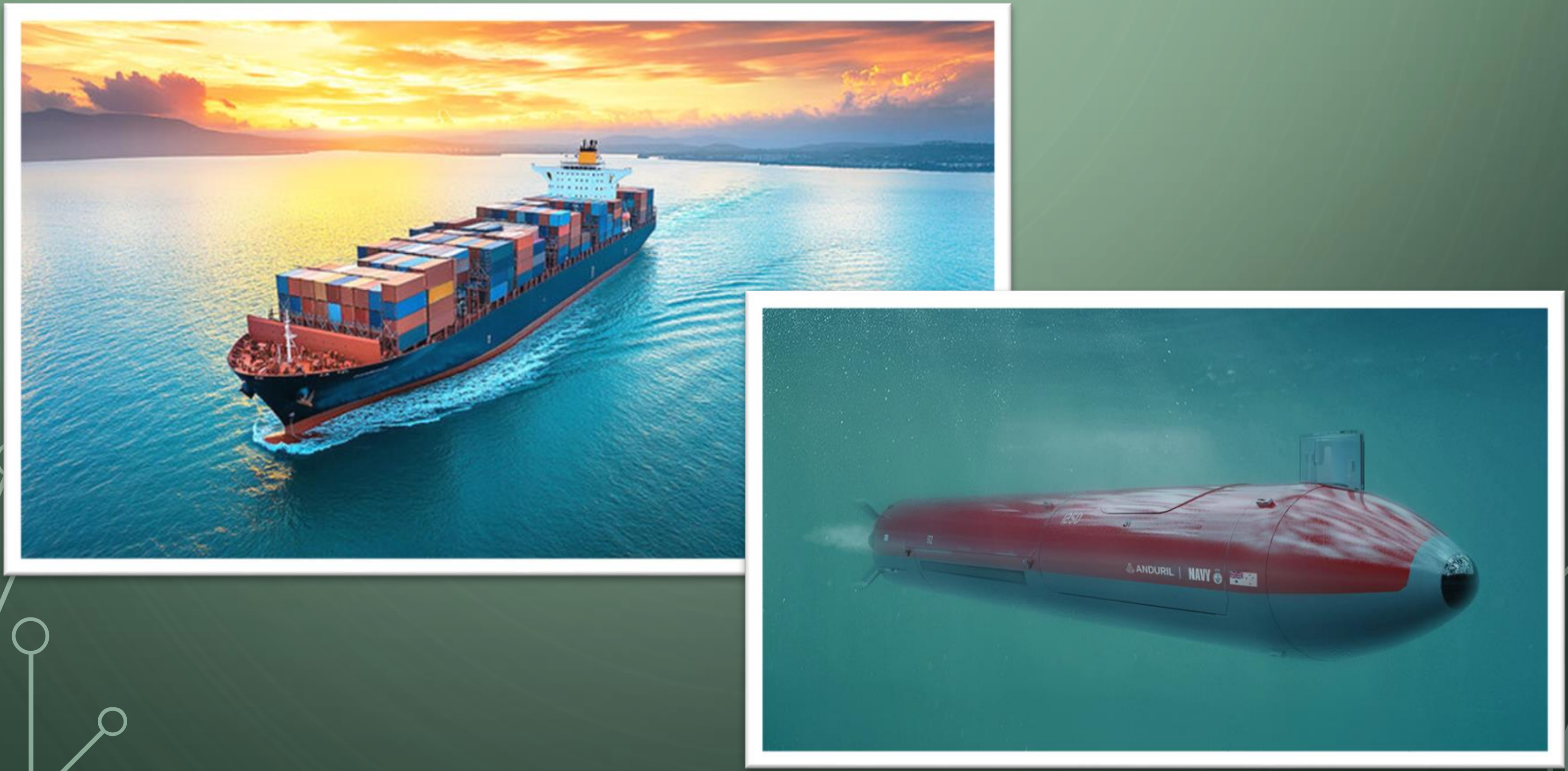


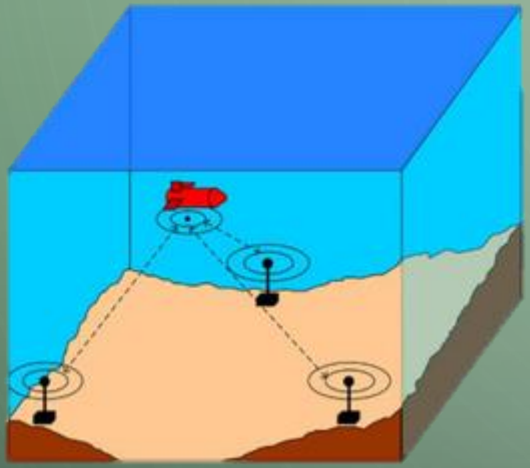
GLOBAL CHALLENGES AND RESEARCH GOAL

- Maritime transport faces transformation due to climate change, trade growth, and energy efficiency demands.
- Underwater cargo vessels reduce congestion, enhance safety, and offer energy-efficient logistics.

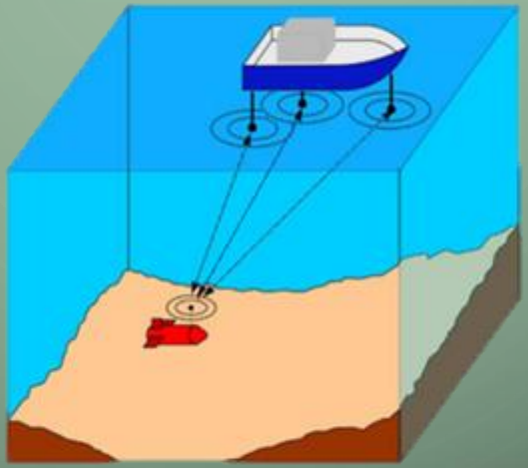


ACOUSTIC POSITIONING SYSTEMS (LBL, SBL, USBL)

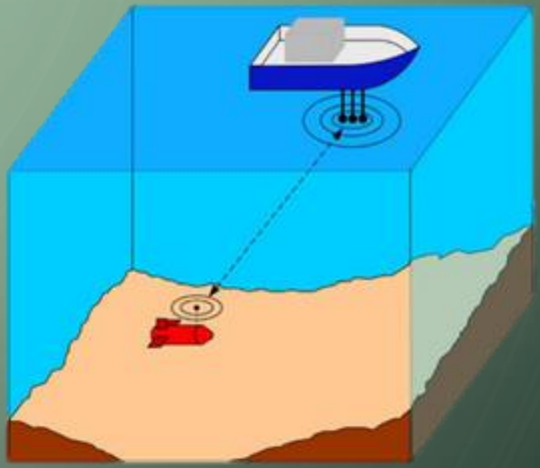
- AUVs combine acoustic, inertial, optical, and magnetic navigation. LBL systems remain most accurate with seabed transponders.



Long baseline system



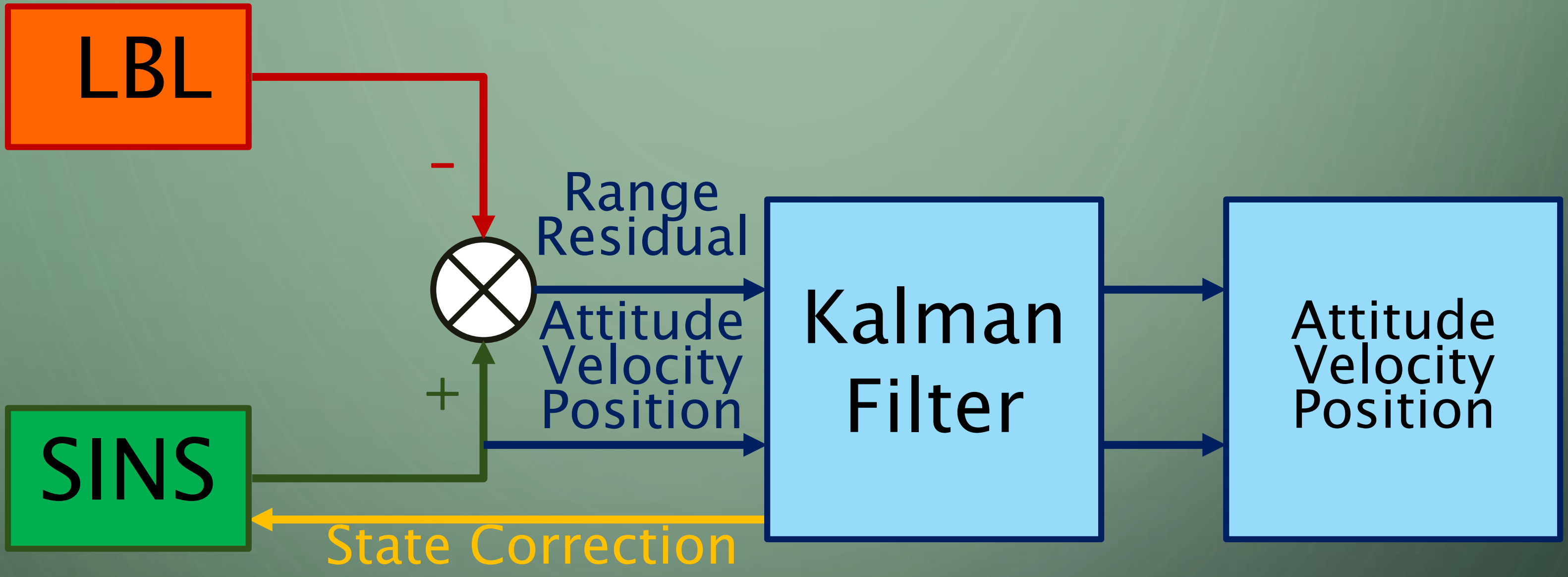
Short baseline system



Ultra-short baseline system

INTEGRATED NAVIGATION ALGORITHMS

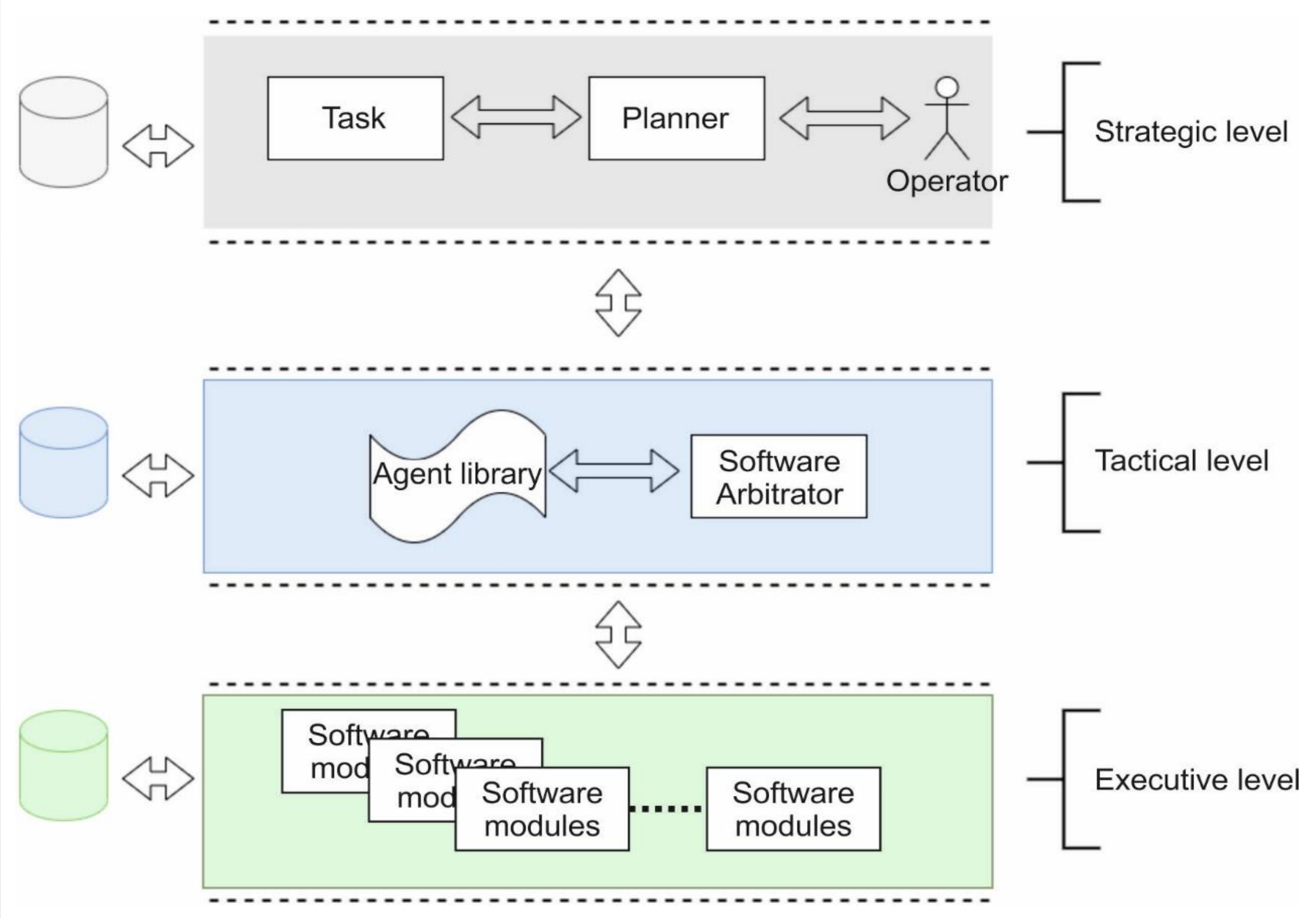
- INS, DVL, and Kalman-based systems maintain precise trajectories even with sensor failures. NARX-RKF predicts nonlinear errors.



Simplified integration of LBL and SINS data using Kalman Filter for attitude, velocity, and position correctio

THREE-LEVEL HYBRID CONTROL ARCHITECTURE

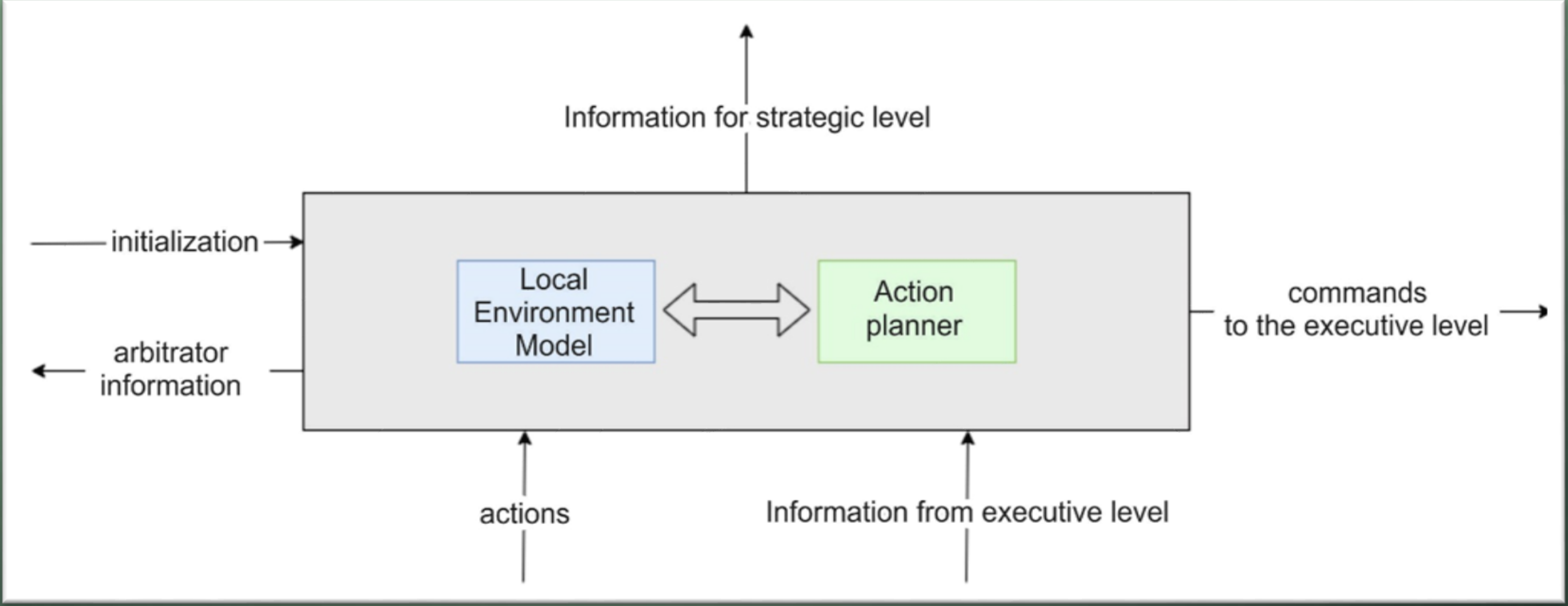
- Hybrid architecture includes strategic, tactical, and executive layers for adaptable mission control.



Hybrid three-level architecture of the AUV software system

AGENT-BASED CONTROL AND ARBITRATION

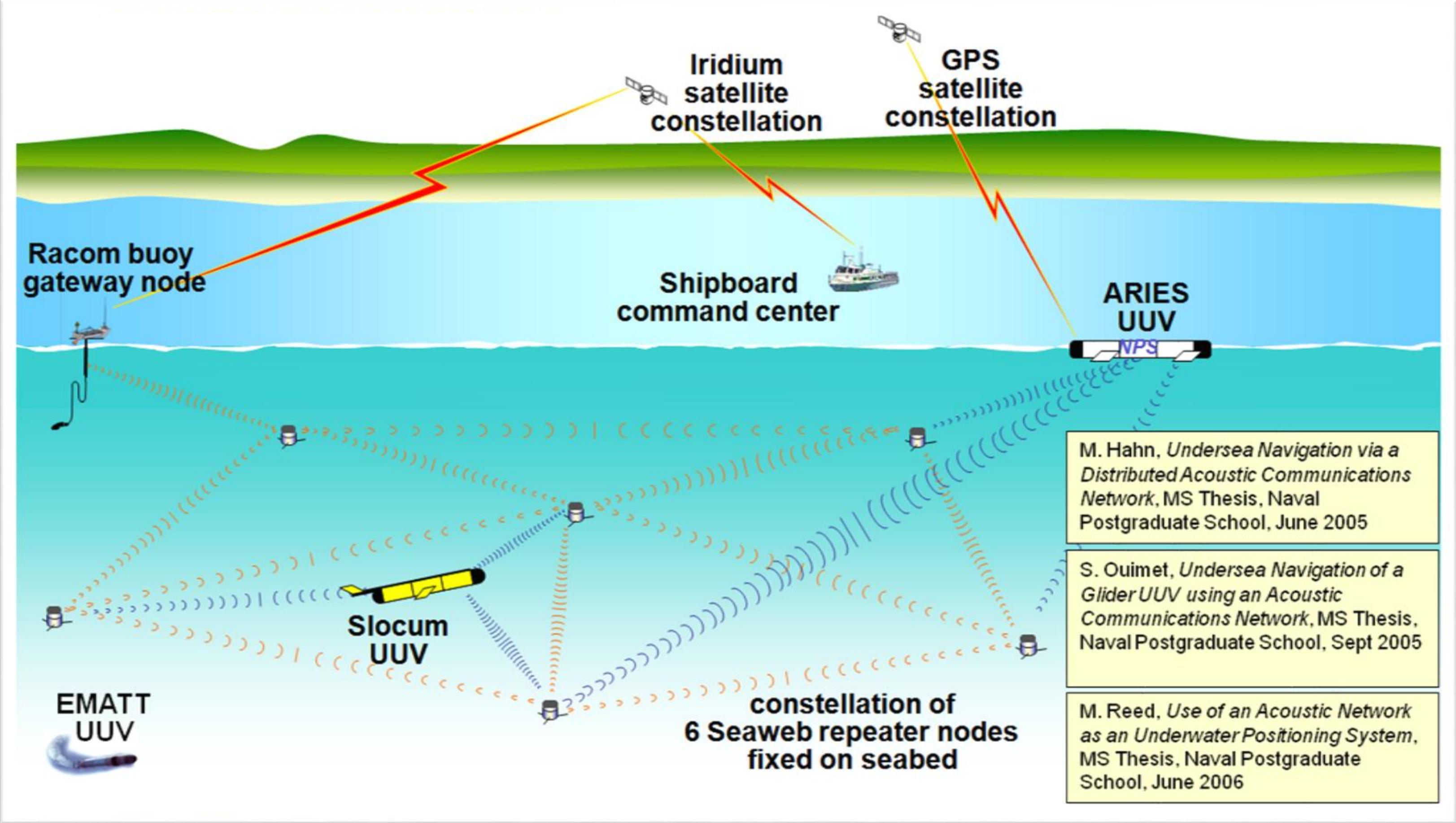
- Agents manage tasks like obstacle avoidance; the arbiter ensures coordination and priority.



Agent-based structure of the tactical level

UNDERWATER SENSOR AND INFORMATION LAYERS

- Sensor and information layers ensure monitoring, data exchange, and submerged AIS functionality.



M. Hahn, *Undersea Navigation via a Distributed Acoustic Communications Network*, MS Thesis, Naval Postgraduate School, June 2005

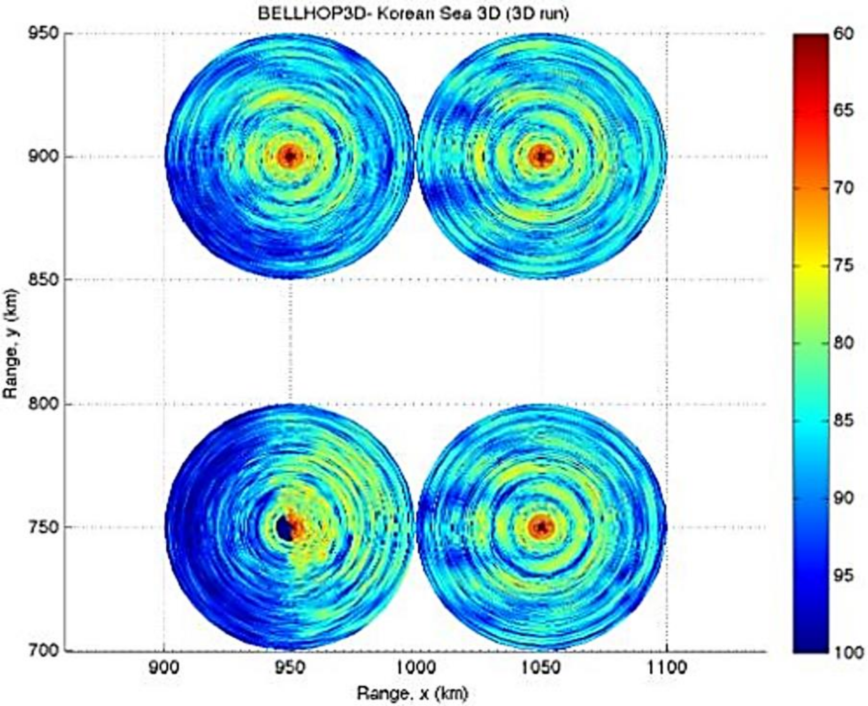
S. Ouimet, *Undersea Navigation of a Glider UUV using an Acoustic Communications Network*, MS Thesis, Naval Postgraduate School, Sept 2005

M. Reed, *Use of an Acoustic Network as an Underwater Positioning System*, MS Thesis, Naval Postgraduate School, June 2006

Scheme of bottom infrastructure of underwater positioning

ACOUSTIC SHADOWS AND VERTICAL ANTENNA ARRAYS

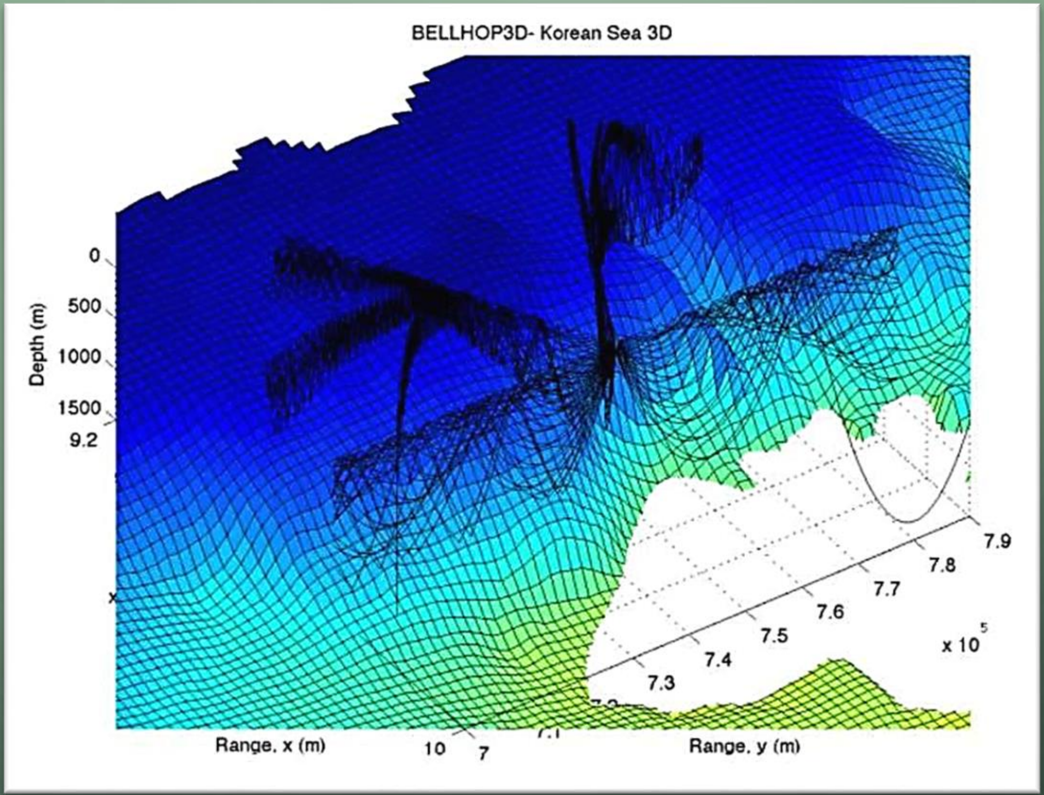
- Vertical antenna arrays mitigate 7–15 km acoustic shadows, stabilizing communication in complex terrain.



Scheme for calculating spatial losses
of an acoustic signal

SOUND PROPAGATION AND BER PERFORMANCE

- Stable communication maintained up to BER 2%. Beyond this, retransmission or alternate channels needed.



Scheme for calculating the trajectory of acoustic rays propagating in the direction of the continental slop

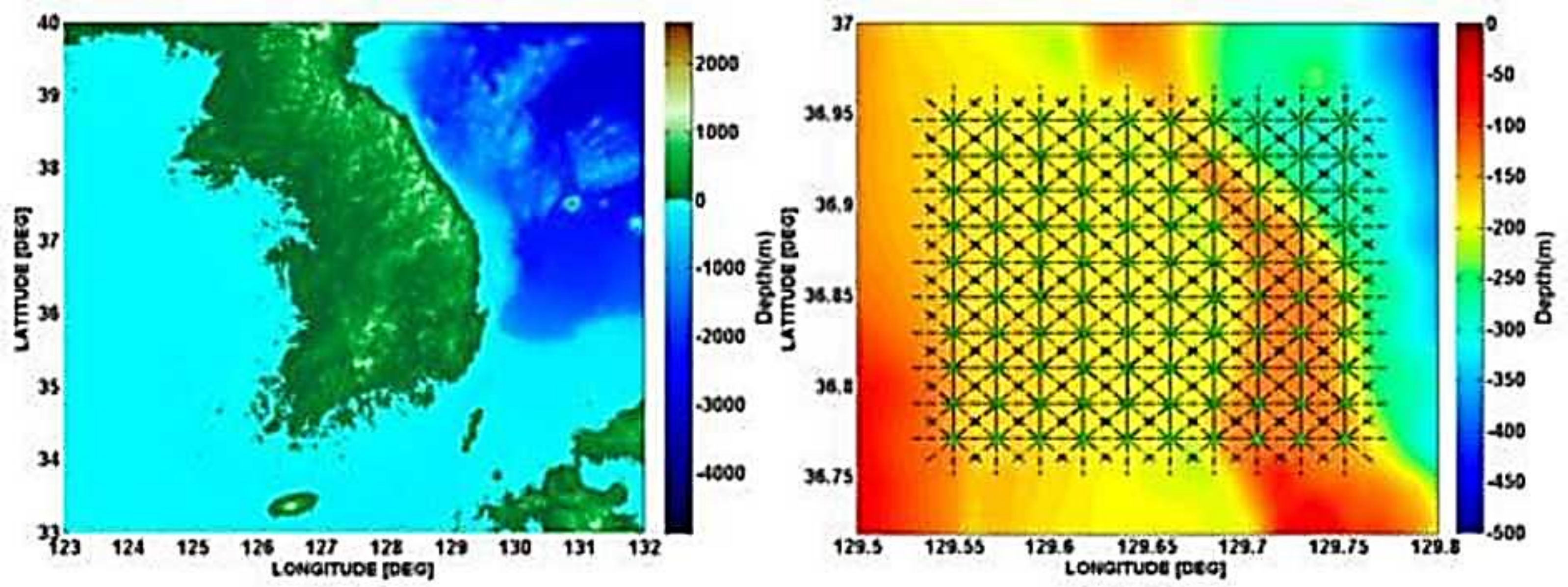
COMPARISON OF UNDERWATER COMMUNICATION TECHNOLOGIES

- Acoustic: long range, low data rate.
- Radio: short range, medium speed.
- Laser: short range, very high speed.

Parameter	Acoustic	RF	Optical
Attenuation	Distance and frequency dependent (0.1–4 dB/km)	Frequency and conductivity dependent (3.5–5 dB/m)	0.39 dB/m (ocean) 11 dB/m (turbid)
Speed	1500 ms^{-1}	2.3×10^{8} ms^{-1}	2.3×10^{8} ms^{-1}
Data Rate	kbps	Mbps	Gbps
Latency	High	Moderate	Low
Distance	more than 100 km	<10 m	10–150 m (500 m potential)
Bandwidth	1kHz–100 kHz	MHz	150 MHz
Frequency Band	10–15 kHz	30–300 MHz	5 x 10^{14}Hz
Transmission Power	10W	mW–W	mW–W

RELAY NETWORK MODEL

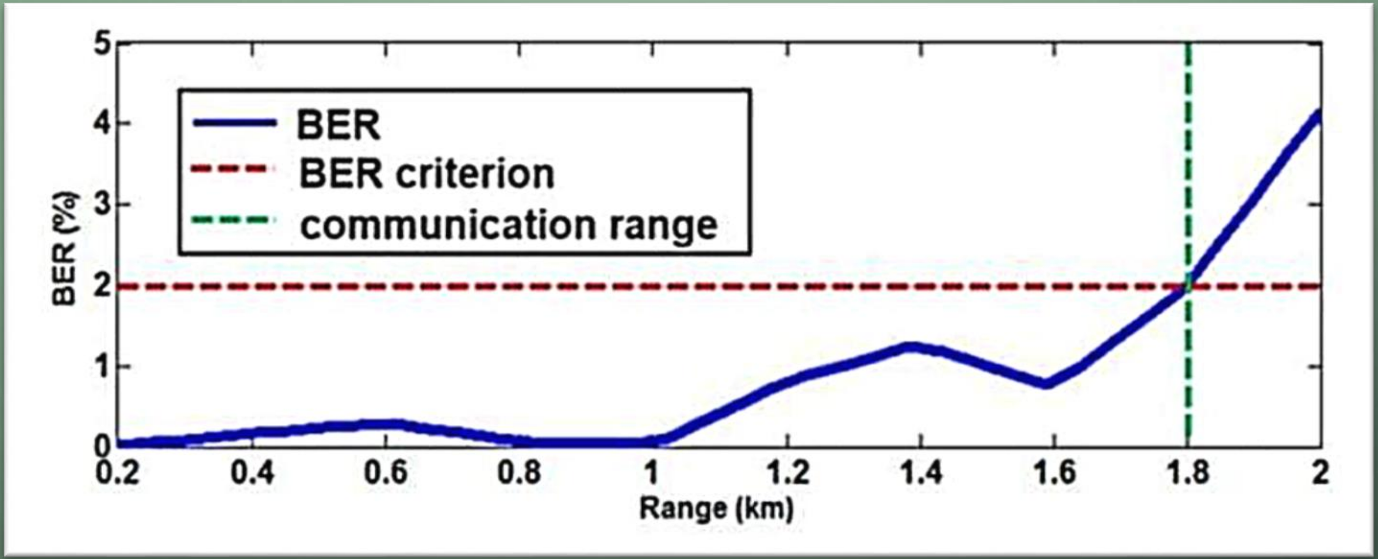
- A 500 km² underwater network with 100 relays achieves >80% coverage and long autonomous operation.



Map and scheme of the acoustic relay network of underwater communication

BER DISTRIBUTION AND COMMUNICATION ZONES

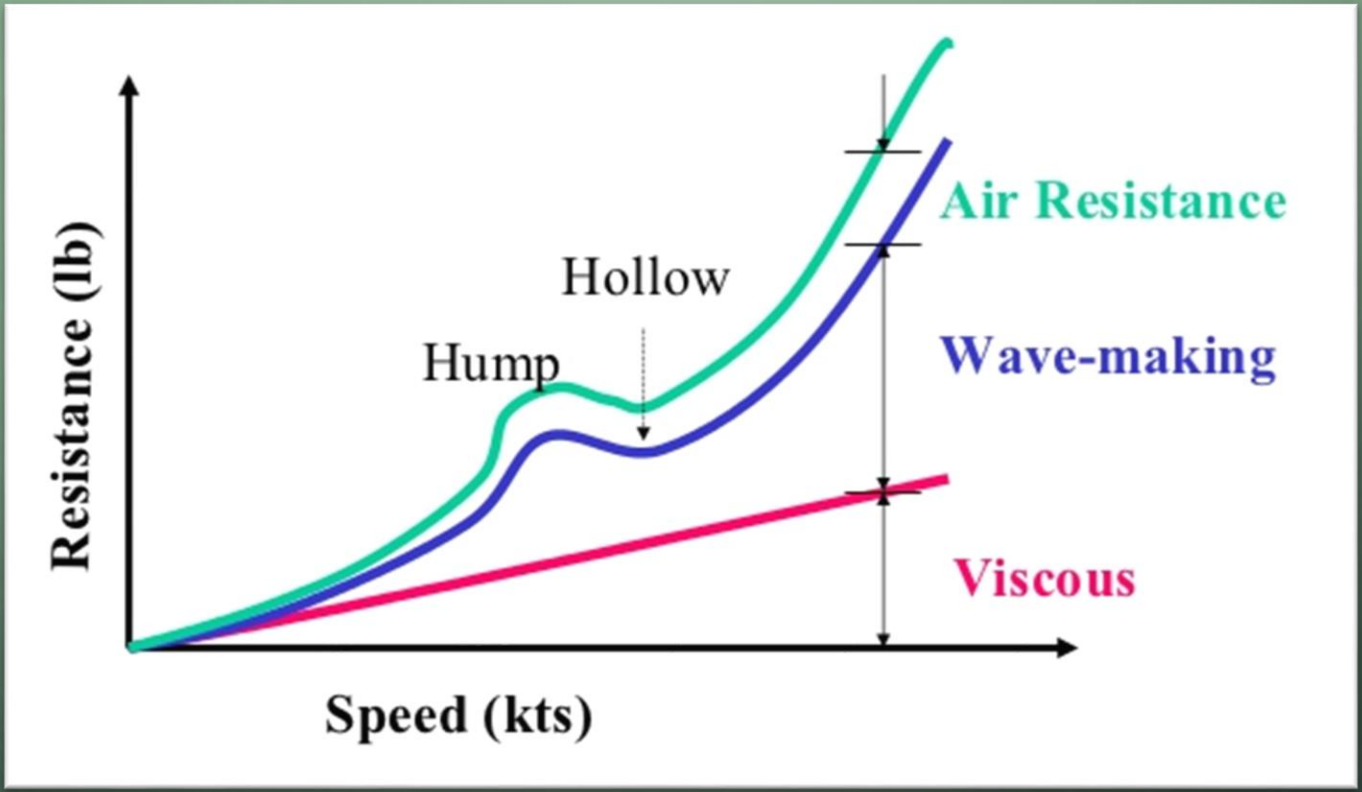
- BER 2% threshold defines the limit of reliable signal coverage and buoy placement strategy.



Example of BER variation as a function of rang

ENERGY EFFICIENCY OF UNDERWATER TRANSPORT

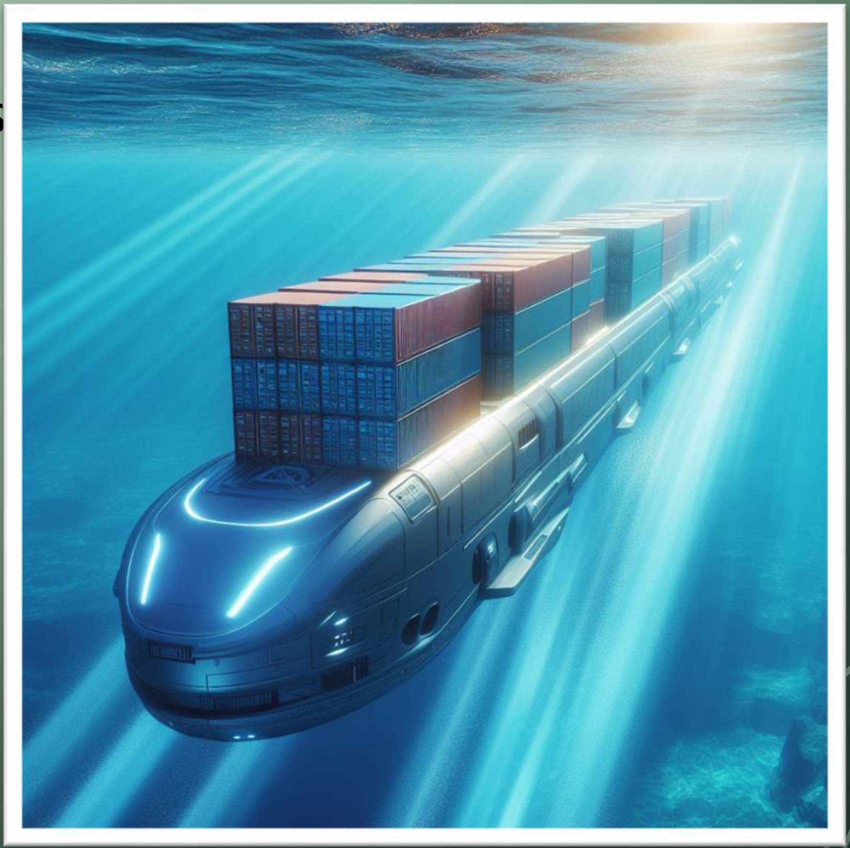
- Submerged navigation cuts fuel use by 20–30%, avoids wind effects, and supports eco-friendly operations.



Components of total hull resistance for a surface vessel

CONCLUSIONS

- 1. High-precision AUV navigation achieved.
- 2. Hybrid control ensures autonomy.
- 3. Civil underwater network feasible.
- 4. Hybrid communication –
  next step in ocean logistics

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