Emerging Undersea Signal Processing Challenges for Future Navy Systems

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ACCELERATING TO THE NAVY & MARINE CORPS AFTER NEXT

Anti-Submarine Warfare (ASW)

THE DIPLOMAT

ASIA DEFENSE | SECURITY

Russian Submarines: Still a Relevant Threat?

A resurgent Russian submarine capability presents considerable challenges for the United States and allied powers.

By Arnaud Sobrero
February 11, 2021

Credit: Flickr/Jens Hoffmann

As the world adjusted to the collapse of the Soviet Union in

USNI News

NEWS MENU SEARCH

Home » Budget Industry » Chinese Increasing Nuclear Submarine Shipyard Capacity

Chinese Increasing Nuclear Submarine Shipyard Capacity

By: H I Sutton
October 12, 2020 11:42 AM

H I Sutton Image. Used with permission

As China pushes to become a blue-water power, nuclear-powered submarines are critically important to Beijing's plan. Historically the Chinese Navy's (PLAN) nuclear-powered submarine fleet has been constrained by its limited construction capacity. There is only one

THE NATIONAL INTEREST

Published on *The National Interest* (https://nationalinterest.org)

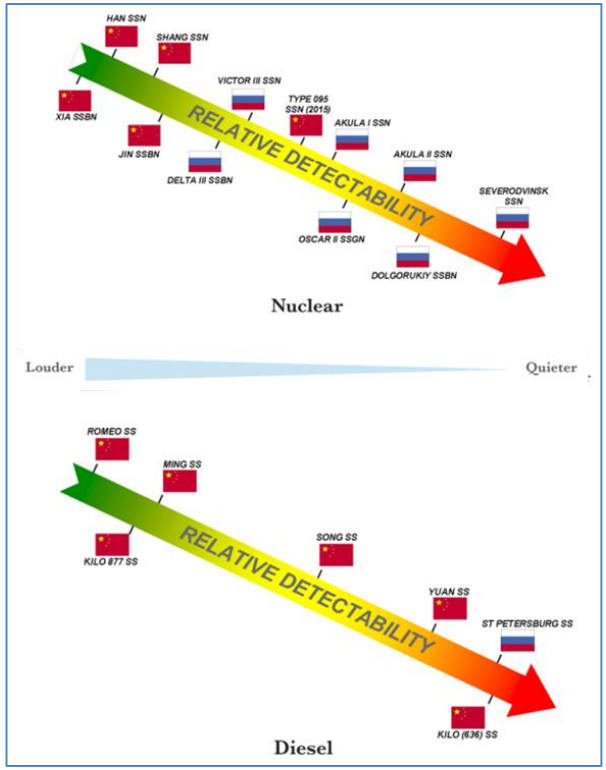
Home > Silent Threat: Why Iranian Submarines Still Matter to the Navy

Silent Threat: Why Iranian Submarines Still Matter to the Navy

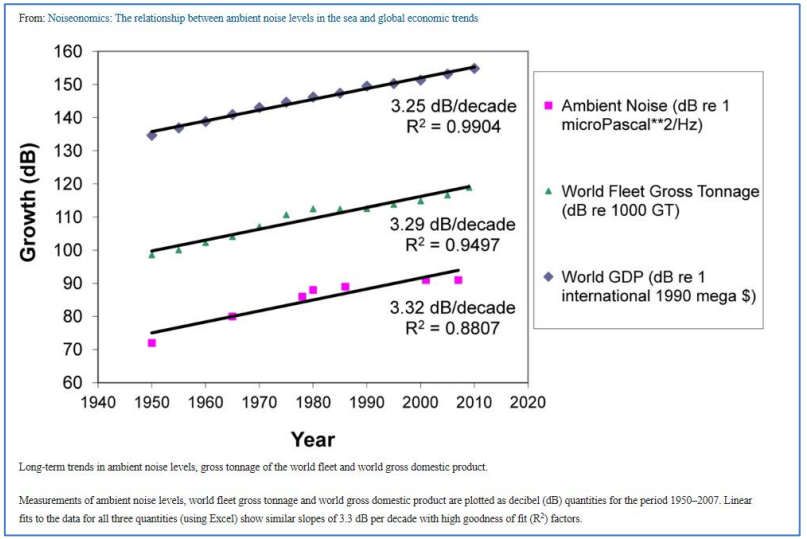
January 22, 2021 *Topic:* Security *Region:* Middle East *Blog Brand:* The Reboot *Tags:* Iran, Middle East, Submarines, Navy, U.S. Navy, War

https://missilethreat.csis.org/wp-content/uploads/2017/04/MissileThreat_RussiaCruiseMissile_map.jpg

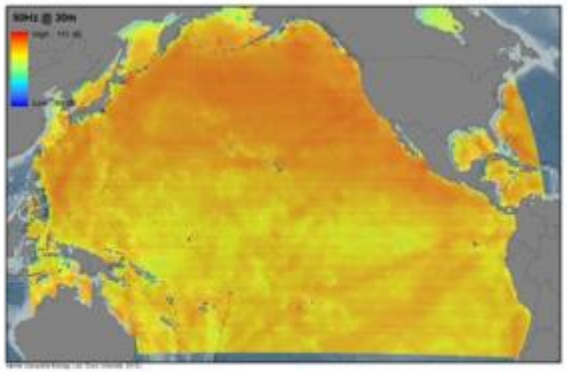
Submarine Signal vs. Noise Trends



US Congressional Research Service, "China Naval Modernization: Implications for U.S. Navy Capabilities - Background and Issues for Congress, " November 1, 2017 (RL33153)



https://www.nature.com/articles/srep00437/figures/4

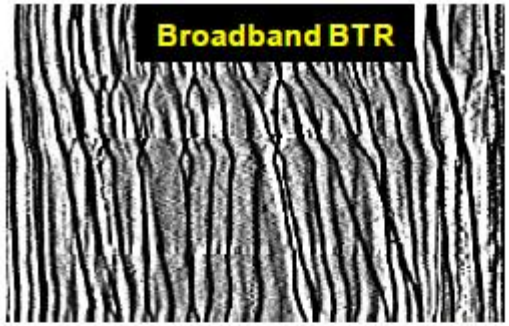


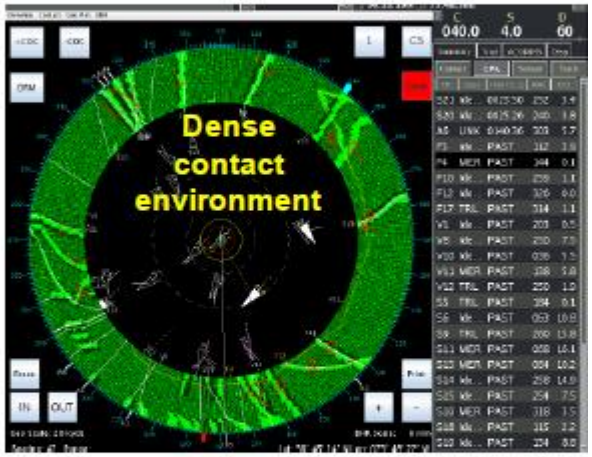
Average annual noise level in the Pacific Ocean in dB re µPa2/Hz for a frequency of 50 Hz and at 30 m depth due to large commercial ships. Image credit: NOAA, https://cetsound.noaa.gov/sound_data.

ASW Systems Trends

- Current trends
  - Increasing operations in cluttered environments
  - More sensors, more capable sensors & processing generate much more data
  - Processing & bandwidth limited in some cases
  - Manpower remains limited, may decrease
  - Potential adversaries' capabilities improving

- Automation improvements are needed to
  - Turn mass of *data* into useful *information* for operators, watch team, and decision makers
  - Build a fused contact picture from multiple sensors (acoustic & non-acoustic) on single/multiple platforms or sensor fields
    - Associated measurements, develop solutions
    - Find Threats & contacts of concern, reduce clutter
  - Exploit external information sources
  - Streamline handling of large search volumes
  - Provide self regulation





Undersea Signal Processing Interests

Broadly, these three major Signal and Information Processing Focus Areas need to be addressed for future Navy systems

1. Exploitation of Environmental Information in Active and Passive Sensing Algorithms

2. Scalable algorithms for new sensor technologies

   - Sensors w/ large number of array elements
   - Multi-sensor / multi-modal fusion

3. Intelligent algorithms to realize full potential of growing sensing capabilities and all information sources

Intelligent Processing

The US Naval Research Enterprise is looking to exploit Artificial Intelligence in future systems to improve capability in many areas of undersea warfare.

EDITORS' PICK | Feb 10, 2021, 11:39am EST | 4,903 views

'Siri, Find Me A Russian Submarine,' U.S. Navy Asks

Michael Peck Contributor

Aerospace & Defense

I cover defense issues and military technology.

ST PETERSBURG, RUSSIA - JULY 26, 2020: The Petropavlovsk-Kamchatsky diesel electric submarine in the ... [+] ALEXEI DRUZHININ/TASS

N211-073

Intelligent Assistant for Anti-Submarine Warfare

OBJECTIVE:
Develop an intelligent assistant that improves active sonar detection, classification, and tracking and enables operators to maximize the potential of the tactical sonar suite.

N211-011

Ping Strategies for an Intelligent Search using Multistatic Active Sonar

OBJECTIVE:
Develop ping strategies, in a simulation environment, that provide optimized performance for multistatic active sonar fields with a target that actively seeks to evade detection by the sonar field.

Example: A.I. at the Processing Level

Advanced Methods for Deep Learning for Improved Classification of Active Sonar Data

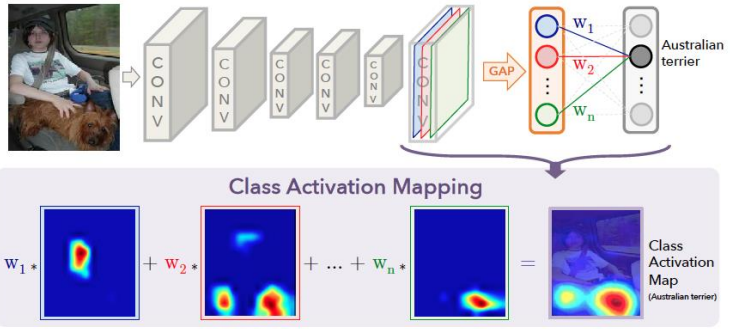
Deep Learning (DL) networks have shown remarkable performance gains for classification tasks in image processing and computer vision and are now considered the state of the art in the field

DL researchers have developed techniques, such as **Class Activation Maps (CAMs)** and **Deep Taylor Decomposition (DTD)**, to determine which elements of the input or internal layers contribute to the output classification decision. These techniques are employed to "explain" the output decision.

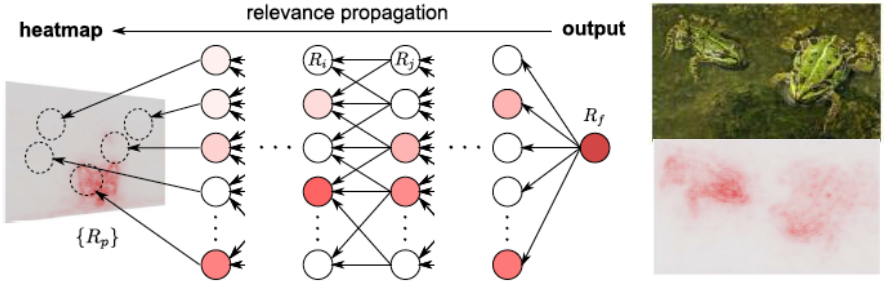
OBJECTIVE

Within a **DL** framework, utilize **CAMs** and **DTD** to develop features for active sonar echoes that improve **target vs clutter discrimination** and/or **clutter type classification**

Class Activation Maps (CAM)



Deep Taylor Decomposition



Challenge: The Problem of Small Data

- Most machine learning techniques are designed for big data, i.e. scenarios huge data sets with hundreds of thousands, millions or even billions of records
- Small data sets are more challenging to handle, require a different set of algorithms and a different set of skills
- Problems of small-data are numerous, but mainly revolve around high variance:
  - Over-fitting becomes much harder to avoid, not only for your training data, but sometimes your validation set as well
  - Outliers become much more dangerous
  - Noise in general becomes a real issue for feature separability
- In the sonar problem space, some of our most important data:
  - Is of modest size
  - Lacks associated environmental information
  - Carries no information about the operator
  - Data cuts from the most important targets are the rarest
  - Usually covers a limited set of environments

https://medium.com/rants-on-machine-learning/what-to-do-with-small-data-d253254d1a89

Example: A.I. at the System Level

Cognitive Sonar

Consider the following definition…

COGNITIVE *adjective*

1) of or relating to cognition; concerned with the act or process of knowing, perceiving, etc.

2) of or relating to the mental processes of perception, memory, judgement, and reasoning

A cognitive ASW sonar system must…

- have memory and the ability to perceive and acquire knowledge of its operating environment
- be able to use this acquired knowledge to reason and automatically change its operating state, e.g. detection threshold or transmit waveform, in order to meet a specific objective
- be able to automatically make judgements to prioritize a set of potentially competing objectives
- be able to interact with the operator and give operator-specified objectives highest priority

Cognitive Sonar Challenges

- Generally, ASW sonar systems employ a static operating state across varying operating environments
  - Current sonar automation is developed to be robust across all operating environments, e.g. classifier training is done using target and clutter data collected from a diverse set of operating environments
  - This is reasonable for static systems, but generally results in suboptimal performance in any specific operating environment
- Limitations of the [human] operator
  - Human-adjustable parameters remain fixed, to reduce workload complexity
  - Sensing capability advancing, information rate increasing and is already well beyond human processing capability
- All contacts are not equal. We "know" how to treat, i.e. preferably set system parameters and allocate resources for, "important" contacts. Indeed, within particular operational contexts…
  - Sea mounts are more important than biologics
  - Surface ships are more important than sea mounts
  - Targets are more important than surface ships
  - Closing near-field targets are more important than far field targets

Key Takeaways

- Threat and environment trends are putting ASW systems requirements in tension
  - Quiet signals in increasing noise demand more and better sensors with more capable detection processing, but
  - The resulting increase in sensor search space places high demands on the operators
    - Clutter drives the workload, not the target
  - Artificial intelligence and machine learning can provide solutions to recover operator attention and focus
- Near term challenges: more and better data
  - More clutter and noise – clutter tends to be high SNR, easier for machine learning
  - More complete environmental knowledge and sensor diversity
  - Better labels and meta-data are the keys to success
- Longer term challenge: artificial intelligence baked into the system architecture

Questions?

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