Insights and Feedback from Long-Term Deployment of an Automated Acoustic Monitoring System for Marine Mammal Detection

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Abstract: *Rtsys, a French industrial SME specializing in underwater acoustic instrumentation, has leveraged the recent advancements in deep neural network algorithms and embedded processors to pioneer real-time, onboard advanced sound signal analysis. This paper presents our inaugural large-scale implementation of such a system, conducted in collaboration with a client in 2024. The project aimed to ensure continuous acoustic monitoring approximately 40 km offshore, focusing on the automatic detection of marine mammals around an offshore wind farm construction site. The data gathered is crucial for adjusting construction schedules and vessel routes based on animal presence.*

We developed a fleet of seven offshore buoys equipped with acoustic measurement and automatic data processing chains, capable of transmitting results via satellite communication while being energy autonomous. The processed data was stored in a database, accessible to the operator via a custom web interface that also allowed for remote configuration of the buoys. Over the twelve-month project duration, we accumulated over 1000 buoy-days of operation.

The primary challenges encountered false positive detections primarily triggered by environmental and anthropogenic noise sources, and sporadic satellite communication interruptions in the operational area. Despite these challenges, the mission was largely successful: system availability was high, enabling the detection of a significant number of marine mammals. The buoys demonstrated resilience against storms and maintained energy self-sufficiency.

This experience underscores the potential of advanced acoustic monitoring systems in marine environments and highlights the importance of robust design and reliable communication infrastructure. The insights gained from this project will inform future deployments and technological improvements in the field of marine acoustic monitoring.

Keywords: *Marine mammals detection, Passive acoustic monitoring, Neural network, Artificial intelligence, Acoustic surveillance*

1. INTRODUCTION

Automated sound analysis methods have traditionally relied on signal processing techniques such as energy detection and matched filtering. However, these conventional approaches frequently demonstrate limited efficacy in detecting and classifying complex acoustic signals in high-noise marine environments.

Recent advancements in machine learning, particularly convolutional neural networks (CNNs), have shown superior performance in pattern recognition tasks. When first adapted for underwater acoustics, these techniques were primarily employed for offline analysis of large datasets. However, such methods typically require substantial computational resources. Over the past decade, advancements in both algorithmic efficiency and hardware capabilities have significantly reduced operational constraints, including:

- Power consumption requirements
- Processing latency
- Implementation costs

These improvements have enabled the development of embedded, real-time underwater acoustic monitoring systems. Automated processing allows for continuous analysis of large-scale acoustic datasets while minimizing human intervention requirements. By implementing onboard, real-time analysis, these systems can transmit relevant acoustic information through low-bandwidth communication channels (e.g., satellite or radio links).

This represents a significant advancement in marine acoustic monitoring capabilities, enabling continuous surveillance across extensive offshore areas that were previously inaccessible to traditional monitoring methods. The technology has potential applications in both environmental monitoring and maritime security operations.

2. OFFSHORE CONSTRUCTION MONITORING APPLICATION

During offshore construction projects, measures must be implemented to prevent harm to protected species. For the construction of the *Coastal Virginia Offshore Wind (CVOW)* and *Vineyard Wind* projects, our client, RPS (USA), commissioned us to design an acoustic monitoring solution to detect marine mammals.

In this project, acoustic monitoring complements visual surveillance. The goal is to detect these animals to avoid initiating pile driving in their presence, thereby preventing harm from underwater noise and reducing collision risks with vessels.

3. OPERATIONAL CONSTRAINTS

The monitoring system was deployed in offshore construction zones located approximately 40 km from shore, presenting several technical challenges:

- Continuous acoustic data acquisition capabilities
- Automated detection and classification algorithms
- Requirements for long-range data transmission
- Near real-time alert transmission protocols
- Operator interface for detection visualization

4. SYSTEM ARCHITECTURE

The monitoring system was structured into four primary functional components:

1. Acoustic Signal Acquisition Module
2. Automated Detection and Classification System
3. Long-Range Communication Interface
4. Operator Visualization Platform

4.1. Acoustic signal acquisition

The system was designed with the following technical specifications:

- Minimum bandwidth requirement of 64 kHz
- Low self-noise characteristics to maximize detection range
- Optimized power consumption for extended deployment durations

To meet these requirements, the system incorporated a high-frequency hydrophone and a specialized acquisition board designed for marine acoustic applications. This hardware configuration supported GPS-synchronized recording capabilities, enabling temporal alignment across multiple distributed monitoring units.

4.2. Automated signal analysis

The detection system utilized deep learning-based classifiers adapted from computer vision applications. The classifiers were developed and trained by an environmental monitoring and research company specializing in marine bioacoustics, specifically optimized to analyse spectrogram representations of underwater acoustic signals.

The embedded system generates multiple spectrogram representations in real-time using varying Fourier transform parameters. Time-frequency regions of interest are then extracted, pre-processed, and analysed by the neural network architecture.

Given the computational demands of the classification algorithms, the primary acquisition board's processing capabilities were insufficient for real-time operation. Therefore, spectrogram computation and neural network inference were offloaded to a dedicated processing unit, while the primary board handled raw data acquisition and streaming.

4.3. Long-Range Communication

Due to the offshore deployment location, the system incorporated Iridium satellite communication capabilities. This communication method was selected based on its balance between power efficiency and sufficient bandwidth for transmitting compressed acoustic data and detection alerts.

4.4. Operator Interface

The system was designed to provide detection alerts to operators in near-real time of the initial detection, accompanied by supporting evidence for validation purposes. To achieve this requirement, a centralized data processing architecture was implemented, featuring:

- Automated data reception and processing pipeline
- Structured database for detection event storage
- Web-based interface for visualization of acoustic parameters and spectrogram representations

4.5. Offshore buoy

The acquisition, analysis, and communication modules were integrated into buoys designed for open-sea conditions with a weight of about 1.2 tons. To ensure energy autonomy, each buoy was equipped with 400W of solar panels and two lead-acid batteries. For ease of maintenance, all electronics were housed in a single watertight enclosure, allowing for quick removal and replacement. The hard drive was placed in a separate compartment on the buoy’s access door for easy swapping at sea.

5. DEPLOYMENT OPERATIONS

The buoys were shipped from France in containers and assembled in Norfolk, Virginia. RPS handled mooring line design and deployment. In early May 2024, the first buoys were deployed offshore of Norfolk, with construction activities beginning in mid-May and lasting until September.

In October 2024, the buoys were retrieved and redeployed for the Vineyard Wind project off Nantucket Island (USA), with operations continuing until December. After a brief pause, the buoy fleet was redeployed in May 2025 offshore of Norfolk, Virginia, for the next phase of the CVOW project, expected to last until September.
Over one year, the cumulative deployment duration reached 1,000 buoy-days.

Figure 1: Deployment of some of the buoys for CVOW, picture credit to RPS TetraTech PSO Group.

6. RESULTS AND CONCLUSION

6.1. Marine Mammal Detections

The buoys successfully detected numerous marine mammals, including dolphins and whales. However, the system experienced false positive detections primarily triggered by environmental and anthropogenic noise sources. Particularly challenging were continuous vessel engine sounds, which exhibited complex frequency and amplitude modulations during engine speed variations. RTSYS plans to improve performance by enhancing mechanical isolation between the buoy and hydrophone and by training neural networks with additional noise data, including vessels engine noise.

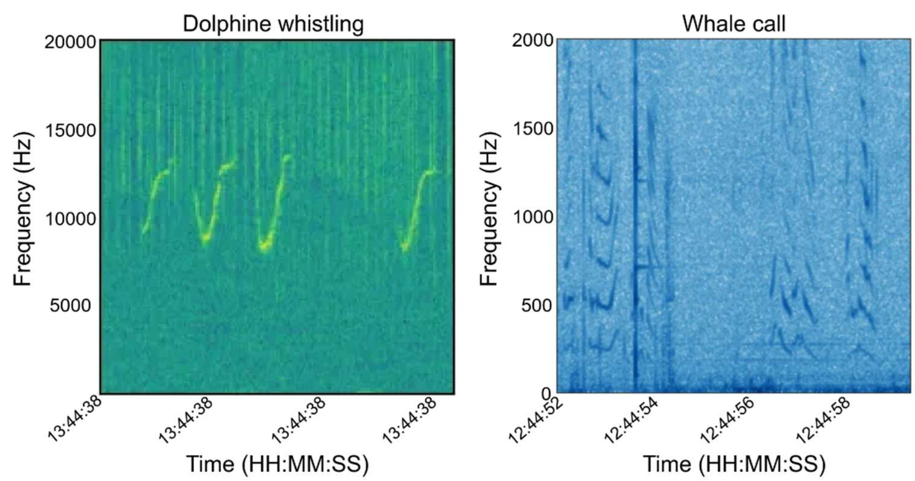

Figure 2: Sample of spectrograms sent by the buoys to the operators during deployment as supporting evidence.

6.2. Reliability

The buoy fleet maintained high availability, allowing construction to proceed as scheduled. Satellite communication proved less stable than expected, with occasional bandwidth limitations even under favorable weather conditions. Message transmission had to be adapted based on available bandwidth, by reducing packet size.

The RubhyAI buoy demonstrated suitability for long-term open-sea deployment due to its robustness, stability, and ample onboard energy. During the Vineyard Wind project, conducted by 41° Nord in a storm-prone area, the buoy fleet maintained high availability.

7. ACKNOWLEDGEMENTS

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