Bluemvmt Client Case Studies

Case Study 1: CubeAI – Advancing Maritime Data Science through Generative AI and Sensor Fusion

Introduction

In collaboration with the Roger F. Wicker Center for Ocean Enterprise at the University of Southern Mississippi, Bluemvmt developed and implemented CubeAI, a hybrid generative AI platform designed to revolutionize ocean data management. CubeAII addresses critical challenges in acoustic Bottom Scattering Loss (BSL) data processing, including error correction, data gap imputation, and real-time decision-making. Traditional data collection and quality control methods in maritime operations are resource-intensive, slow, and often prone to fragmentation. CubeAI's advanced AI capabilities enable efficient, accurate, and scalable solutions for non-experts and experts alike. CubeAI demonstrated the transformative potential of AI-assisted data correction and imputation methods, significantly improving data accuracy and reducing the mean squared error.

This case study delves into Bluemvmt's role in advancing maritime data science by deploying innovative technologies, including the generative AI platform CubeAI. It explores its application in a real-world scenario to detect anomalies in complex underwater environments.

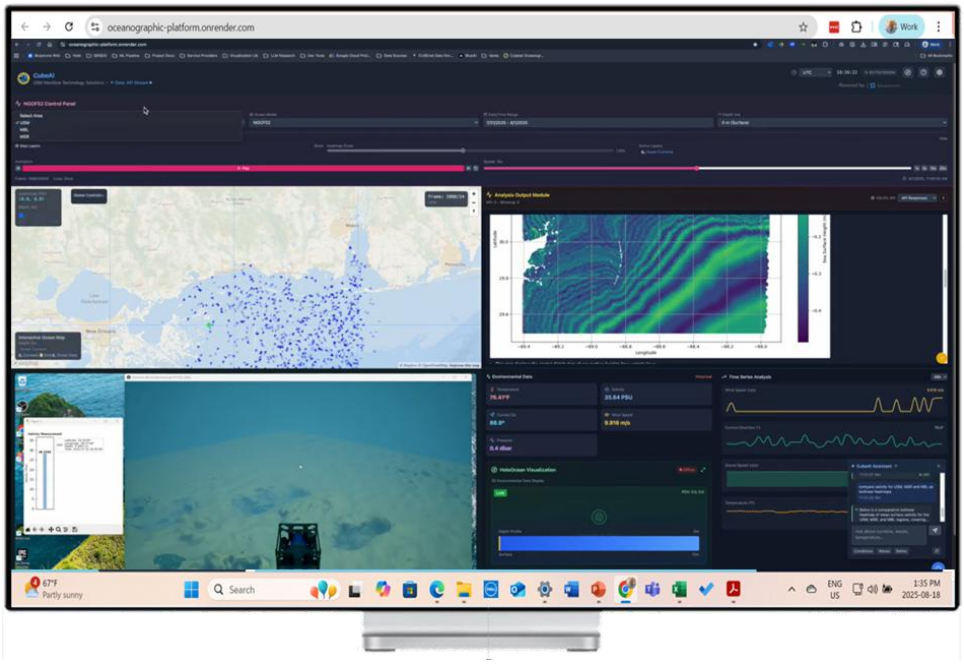

Figure 1 - CubeAI powered by Bluemvmt

Key Challenges in Maritime Data Management

- **Data Fragmentation:** Inconsistent and siloed datasets hinder comprehensive analysis and decision-making.

- **Error-Prone Processes:** Manual QA/QC methods are slow and often inaccurate, compromising data reliability.
- **Gaps in Data**: Equipment malfunctions and environmental factors frequently cause missing values in datasets.
- **Complex Data Environments:** Analyzing data in noisy underwater conditions requires advanced algorithms capable of discerning natural features from man-made artifacts.

Research Focus: Generative AI and Sensor Fusion in Maritime Technology

Research was focused on integrating advanced generative AI capabilities into maritime operations through the CubeAI platform. The objectives were to:

- Enhance data accuracy using AI-driven BSL error correction and imputation techniques.
- Create a robust, SME-centric model for real-time decision-making and operational efficiency.
- Develop advanced sensor fusion methodologies to improve underwater object detection.

Key Innovations and Methodologies

The research introduced several cutting-edge innovations to address long-standing technical challenges:

Generative AI for BSL Data Integrity

- **Isolation Forest Analysis:** AI identified outliers in acoustic data, marking them as missing values for correction.
- **Multiple Imputation Methods:** AI dynamically selected optimal techniques for data gap filling, ensuring alignment with true scattering loss.
- Results showed significant improvements in data accuracy, reducing errors and enhancing the integrity of BSL datasets.

Sensor Fusion with Bathymetric LiDAR and Sonar

- **Fusion Framework:** Multibeam sonar (GSF files) and Bathymetric LiDAR (LAS files) were integrated to create high-resolution underwater terrain maps.
- **Dynamic Sensor Selection:** Adaptive algorithms choose optimal sensors based on environmental conditions, ensuring precise data acquisition.

Real-Time Predictive Analytics:

- AI models integrate real-time environmental factors (e.g., salinity, temperature, and pressure) to refine predictions and support tactical operations.

Reinforced Human Feedback Loop (RHFL)

- SMEs provided iterative feedback to refine AI model predictions, enhancing accuracy and operational relevance.

Blockchain for Security and Traceability

- Blockchain technology ensures tamper-proof logging of data and model activities, supporting auditability and compliance.

Interactive Generative AI Tools

- A RAG-based chatbot enabled SMEs to query and interact with BathyAI using natural language, reducing the time and complexity of data interpretation.

Results: Acoustic Bottom Scattering Loss Data Processing

Bottom Scattering Loss (BSL) is a key parameter in naval operations, affecting sonar performance and underwater communication.

AI Implementation:

- CubeAI employed Isolation Forest analysis to detect anomalies in BSL data. The AI identified 30 outliers in a dataset of 261 entries based on variables such as grazing angle, frequency, and scatter strength.
- For data gap imputation, four methods were tested:
    - **KNN Imputation:** Leveraged local data similarities for accurate predictions.
    - **Random Forest Imputation:** Demonstrated the lowest error rates, making it the preferred method.
    - **MICE and Mean Imputation:** Served as alternatives with slightly higher error metrics.

Results:

- **Accuracy:** AI assistance improved Data processing accuracy from 85.2% to 95.8%.
- **Efficiency:** Time for data processing was reduced from 4 hours to 12 minutes.
- **Error Reduction:** Mean Absolute Error (MAE) decreased significantly, ensuring higher data reliability.

