MobyGlobal: Real-Time Right Whale Detection Network Powered by a Two-Branch Ensemble Learning Model on 3D-Printed Buoys

(Icons from Flaticon)

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PURPOSE

North Atlantic Right Whales are critically endangered. Around 370 Right Whales remain, with only 70 fertile females (Szabo, 2018). Additionally, scientists estimate that one-third of right whale deaths are unrecorded (NOAA, 2025). Since 2017, there has been a 20% population decline (NOAA, 2025).

Human interactions are the leading cause of Right Whale deaths and injuries (Gannon, 2012; NOAA, 2025; Figure 1). The primary causes are fishing net entanglements and vessel collisions (Figure 2).

These two interactions are **preventable** when whale locations are known because net placements and ship routes can be modified to prevent encounters.

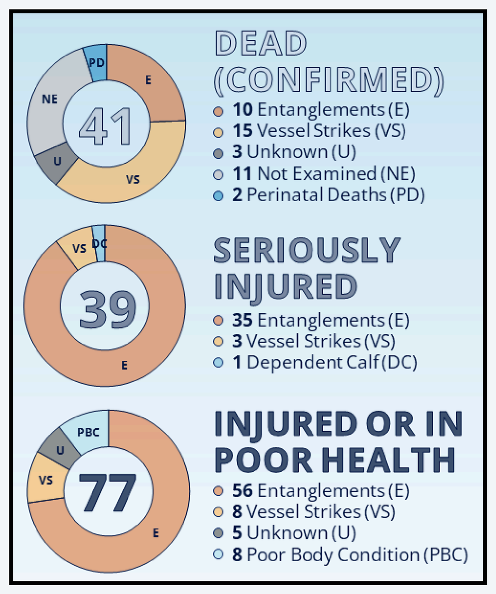


Figure 1. North Atlantic Right-Whale death and injuries 2017-2025 due to human activities in Unusual Mortality Event (modified from NOAA, 2025)

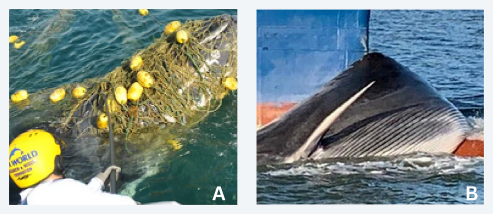


Figure 2. A) Whale Ship Collision Result (Kurmelovs, 2022) & B) Whale Net Entanglement (IFAW, 2022)

Location information about whales is currently **limited** (NOAA, 2025). Whale tracking is mainly done through whale tagging and aerial scanning. Whale tagging is an invasive procedure that causes blunt trauma (Weller et al., 2008; Figure 3) and requires **expensive** monitoring equipment - $2400 per whale (IFAW, n.d.). Because Right Whales are solitary, tag monitoring can only track one whale at a time. Aerial imagery provides a historical location and doesn't provide the ability to continuously track locations (Figure 4); This results in **temporal gaps** in available whale location data (Marine Mammal Commission, 2024). Additionally, vast regions of the ocean are unmonitored.

Current Solutions for Whale Tracking are Insufficient:

Tagging and Aerial Scanning.

Figure 3. Whale Tagging Causes Trauma and Damage (IFAW, n.d.)

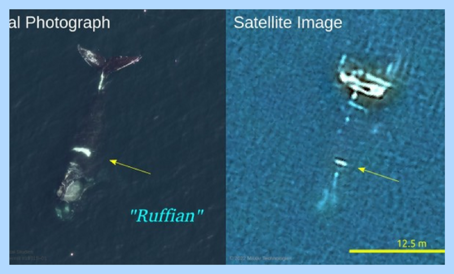


Figure 4. Aerial scans aren't able to track continuously or in real-time. (Image from Bessel, 2023)

Whales and other cetaceans are known to have **distinct calls** that can be differentiated from ocean noise (Figure 5; NOAA, n.d.). Additionally, whale calls can travel thousands of miles (Matthews, 2021). Therefore, a tracking system on whale calls can provide an **inexpensive and continuous** solution whilst being unobtrusive.

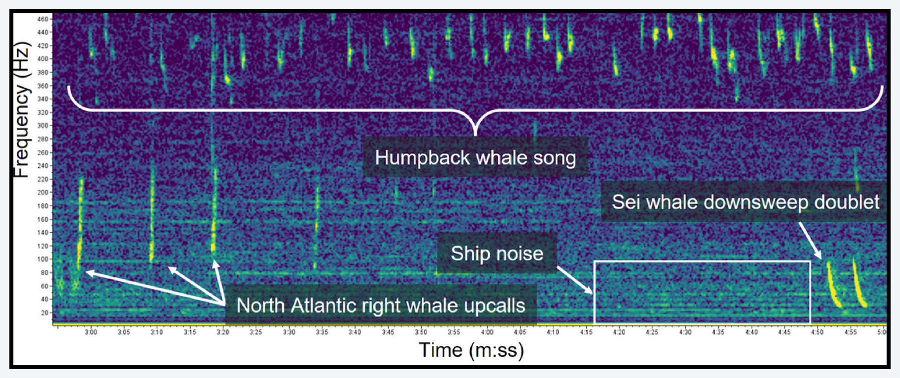


Figure 5. Spectrogram demonstrating easily distinguishable common aquatic sounds (modified from NOAA, n.d.)

ENGINEERING OBJECTIVE

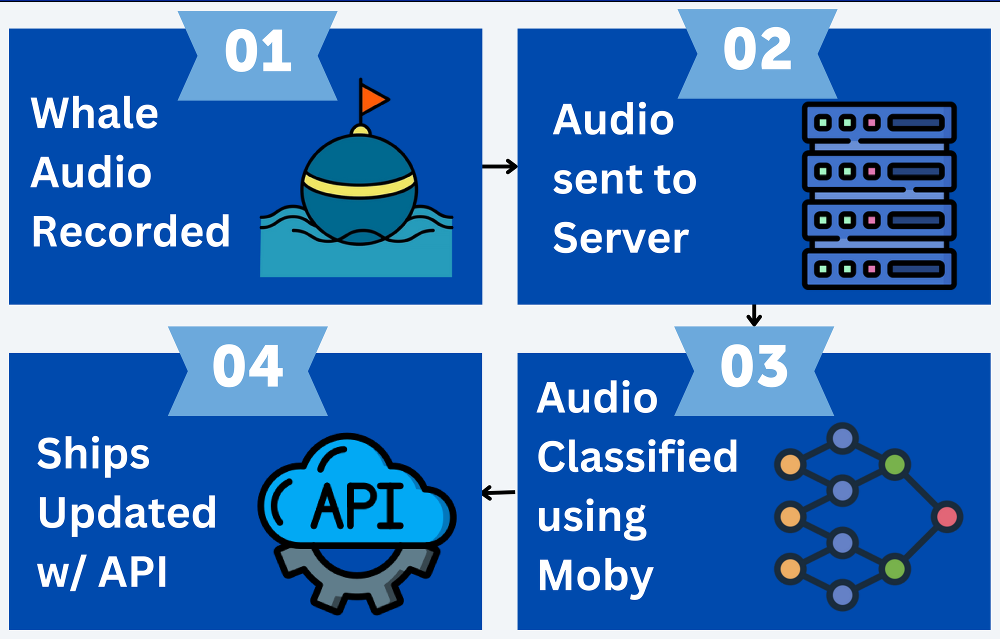
Track Right Whale populations through detection of auditory whale calls

Accurate	Replicable	Real-Time
Low error in classifying sounds	*Easily scalable for coastal coverage*	*Low latency in detection and update*

SOLUTION CRITERIA

(Icons from Flaticon)

SOLUTION OVERVIEW



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WHALE AUDIO CLASSIFICATION

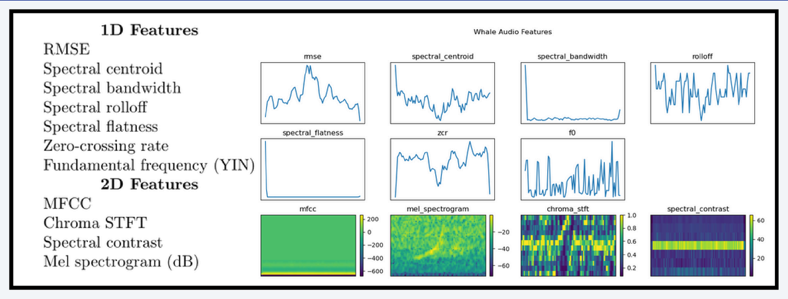

Figure 6. The data was pre-processed into features using 11 extraction methods, resulting in seven 1D features & four 2D features (bottom images) shown above (Image created by researchers)

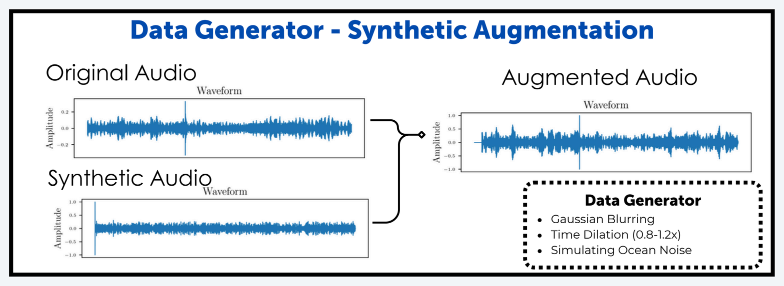

Figure 7. Data was augmented using Gaussian Blurring and Time Dilation to introduce ocean noise (Image created By researchers)

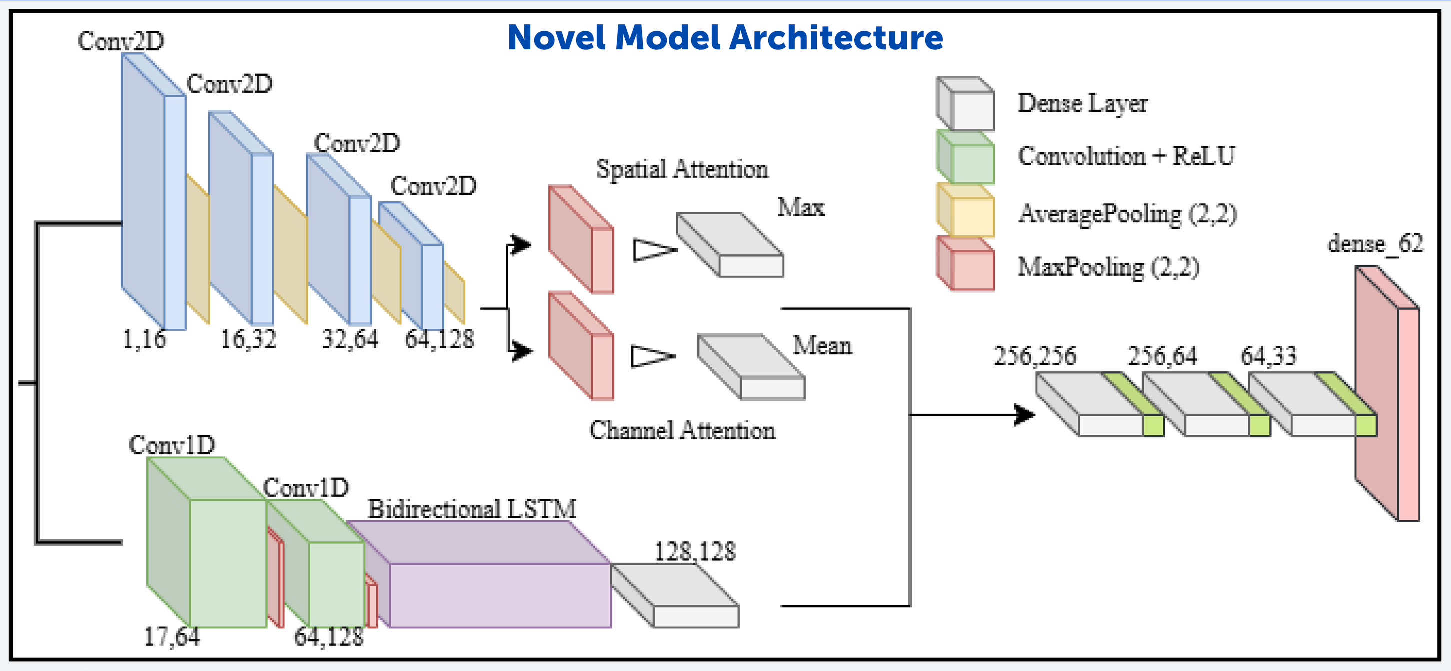

Figure 8. A two-branch ensemble learning model (Moby) was made to classify whale audio. The 2D-branch uses 2D convolutions in a Convolutional Block Attention Module. The 1D-branch combines 1D convolutions and Long Short Term Memory modules. These features are combined into a neural network to create a softmax prediction. (Image created by researchers)

Data Preprocessing

- The audio dataset was from Cornell University, the Watkins Marine Mammal Database, and NOAA (Cukiersk, 2013). It contained 30,000 clips of labeled Right Whale and ambient ocean audio.
- The data was **pre-processed** by extracting 7 types of 1D harmonic features and 4 types of 2D spectral features (Figure 6).
  - Spectral features describe the shape and distribution of frequencies. Harmonic features relate to pitch, harmony, and tone.
- Gaussian blurring and time dilation were used to **augment the dataset** and allow the model to differentiate in different conditions (Figure 7). Data was split into training (70%), validation (15%), and testing (15%) sets using **K-Fold cross validation**.

Training/Testing

- A two-branch **ensemble model** (Moby) was trained for whale audio classification using a Convolutional Block Attention Module for 2D data and an LSTM feature branch for 1D data (Figure 8).
- Performance in AUROC score and accuracy was compared to traditional CNN-based models (families of Resnet, VGG, and EfficientNet; shown in Figure 9).
- Results show a higher AUROC score with fewer parameters when compared to conventional models for audio classification.

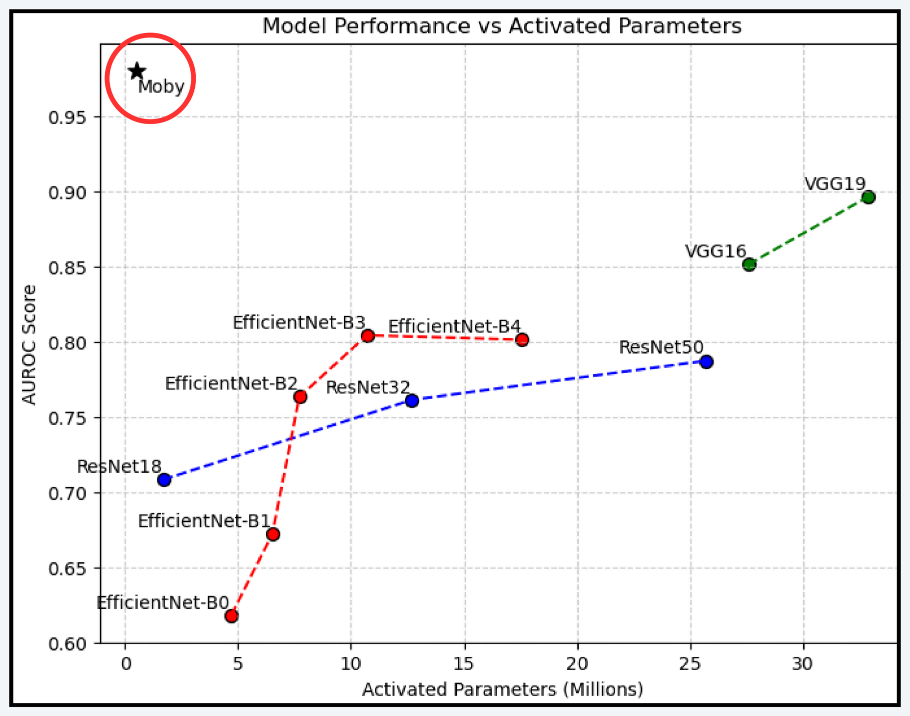

Figure 9. A comparison of model performance (AUROC score) vs parameter count when classifying Right Whale sounds. Moby showed a lower parameter count (343,877) with a higher AUROC score (0.977 ± 0.002) than pre-trained conventional CNN image recognition models (Image created by researchers).

MOBYGLOBAL NETWORK & API

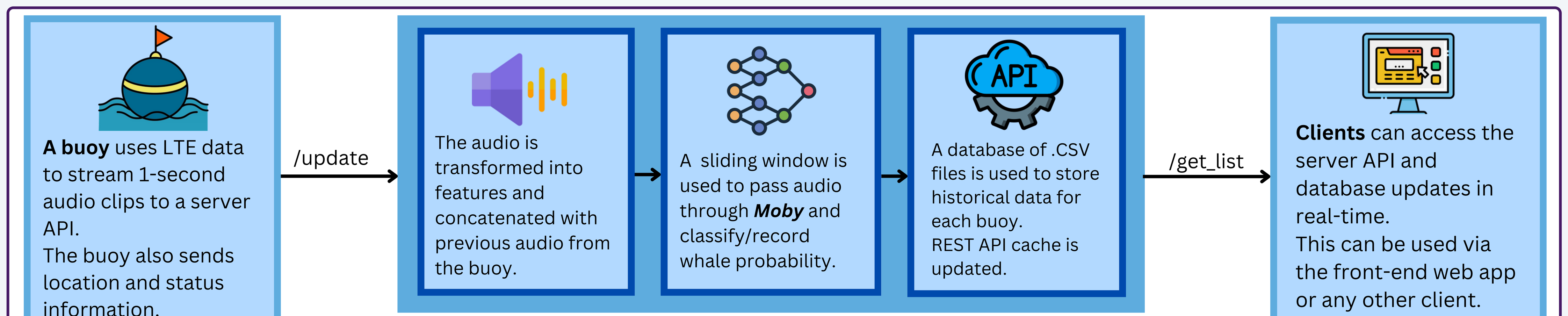

Figure 10. Data flow between buoy (left), server (middle), and client (right). (Figure Created by researchers, Icons from Flaticon)

The server pipeline uses a REST API for processing buoy updates (Figure 10). A client app using the MobyGlobal API was created for testing using vanilla JS (Figure 11).

Apache benchmark was used to send 1000 requests to the server for testing. Results show an average response time of **26 ms** between client and server (Figure 12). The server's processing time was also tested, yielding an average of 486 ms per buoy update.

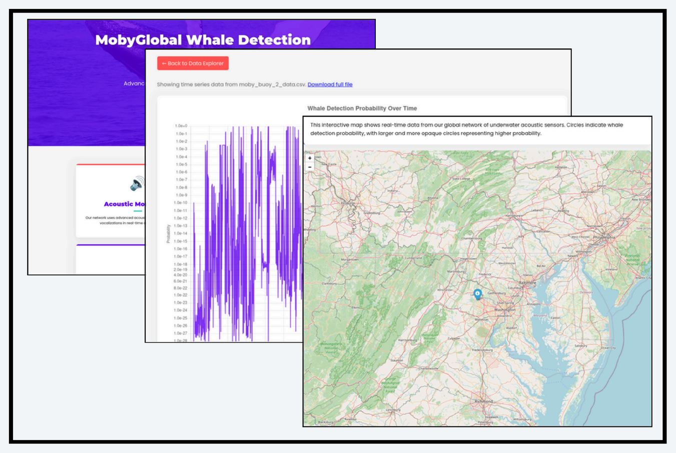

Figure 11. Screenshots of a webapp built with HTML/CSS/JS created to test the capabilities of the MobyGlobal API. (Website and screenshots were created by researchers)

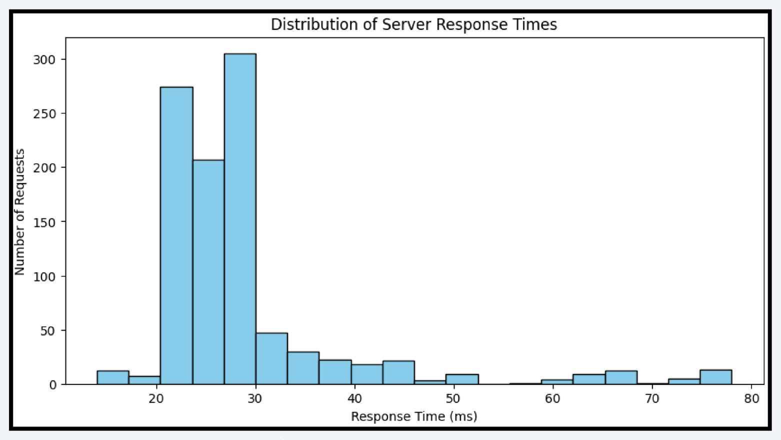

Figure 12. A histogram of server-client response times with Apache benchmark. Server response time distribution on average is 26 ms, with a skewed right distribution. (Image created by researchers)

BUOY DESIGN & TESTING

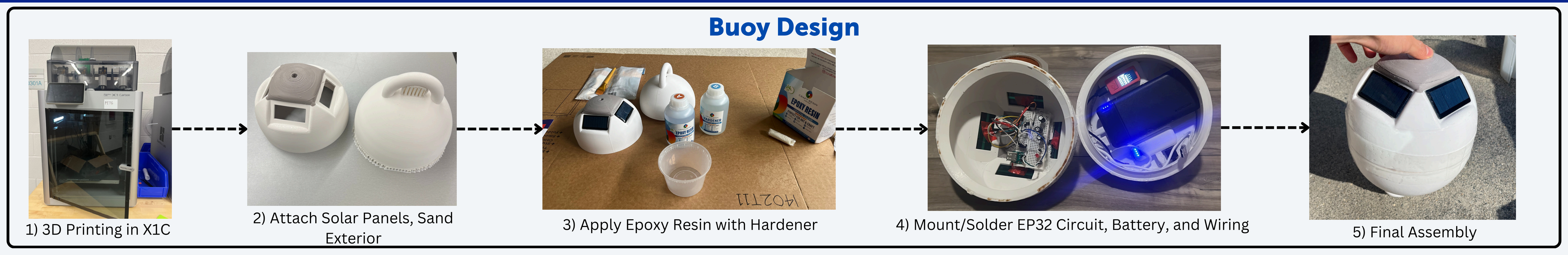

Figure 13. After 3D printing, the buoy was sealed with epoxy resin to ensure waterproofing. Onboard electronics consist of an M5Stick-style ESP32, which in full deployment will interface with an LTE modem and a hydrophone; during benchmark tests, Wi-Fi and a standard microphone were used instead. All components—the ESP32, battery, and solar panels—are wired on a breadboard mounted to the buoy's lid and powered via USB from a dual-battery pack. (All images taken by researchers)

A scaled version of the Good Buoy design from T3chFlicks (sk-t3ch, 2021) was evaluated for stress factors under ocean conditions using a **Von-Mises stress test** (Figure 14A). The buoy was then 3-D printed, and onboard electronics were added and enclosed with the final assembly (Figure 13). The buoy was tested for buoyancy and stability inside an outdoor pool (Figure 14B).

The electronics were fully powered in sunlight. Without sunlight, the electronics can function for **72 hours**. The overall design costs $442 to build (Table 1).

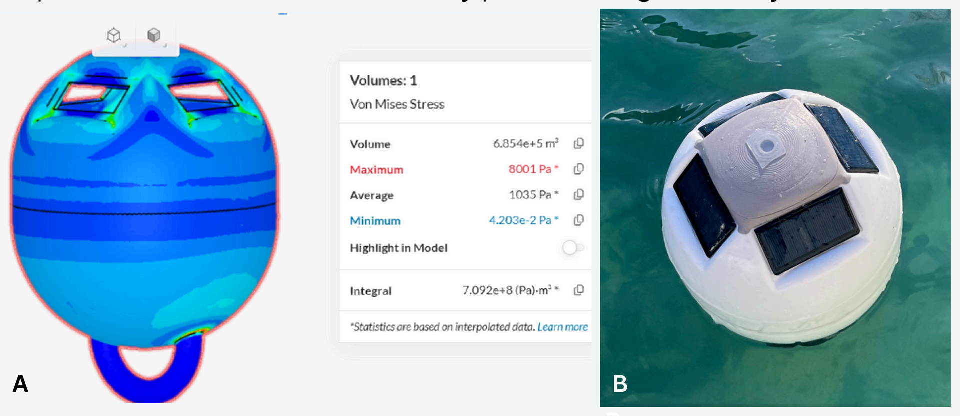

Figure 14. Results of a Von-Mises Stress Test on the buoy tested in SimScale. Accounted for gravity, water pressure, wave forces, drag, etc. Used literature to predict the max tough conditions for PETG (50 MPa) for both fluid & static forces. The maximum stress of ~0.008 MPa (highlighted in red) was below the 50 MPa limit of PETG, confirming a strong design. A field trial was then conducted on the buoy, demonstrating buoyancy and stability in a pool test. The buoy was found to be self-righting when disturbed. (A - Graphic created by researchers in SimScale; B - Photograph taken by researchers)

Product	Cost
5v 60mAh Solar Panels	$15.00
PETG Filament	$20.20
Epoxy Resin	$66.66
M5 Stick / ESP32	$20.00
Aquarian A5 Hydrophone	$200.00
Cables & Wires	$5.00
UPhoria UM2 Sound Card	$40.00
2x 10k mAh batteries	$35.00
LTE Module	$40.00
Total	**$441.86**
Wireless data cost (yearly)	$420.00

Table 1. The buoy's estimated cost breakdowns, with the total module costing around $440. A hydrophone and a sound card were not purchased in the current prototype, but are needed for deployment. (Table created by researchers)

DISCUSSION

WHALE AUDIO CLASSIFICATION

Moby's high AUROC score (0.98) passes the benchmark (0.72) set by Cornell (Scipy, 2013). Moby is the most efficient model as it uses far fewer parameters than conventional CNN models while being more accurate.

MOBYGLOBAL NETWORK & API

Testing of the server shows that the system is working in real time with a processing time of less than 0.5 seconds.

BUOY DESIGN & TESTING

The Von-Mises Stress Test shows sufficient theoretical durability, with pressure well below the maximum pressure of PETG Filament. In physical testing, the buoy proved buoyant, watertight, and resistant to external perturbation forces. The buoy is potentially **self-sufficient** with the solar panels, as the batteries allow up to 3 days of recording and updates without sunlight.

SOLUTION ADJUSTMENTS

- The initial processing occurred on the buoy, unable to keep up with the incoming stream of data. Thus, audio processing via Moby was **transferred to the server-side**.
- The buoy's processor was changed from a Raspberry Pi to an ESP32 due to **lower power costs** for the ESP platform.
- Moby (detection model) was changed from a pure CNN to a CBAM model to **increase detection accuracy**.

FUTURE DEPLOYMENT

BUOY DEPLOYMENT REQUIREMENTS

- The buoys' sites should **minimize environmental impact** on marine habitats (Viola, 2025).
- The US Coast Guard (USCG) needs to approve the buoy to be deployed in US waters.
- A suitable anchor system needs to be developed for stability.
- Once deployed, the USCG should be informed of the location of the buoys to **publish on maps**.

DEPLOYMENT PLAN

- To be deployed in a network of ~133 buoys, each occupying a radius of **13 nautical miles** (Figure 15).
- Request the USCG to publish on buoy maps.
- Use an **anchor system** with a weight (Figure 16).

Figure 15 East Coast Buoy Deployment Map (Image Created by Researchers)

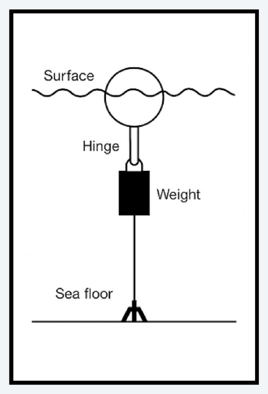

Figure 16. Buoy Deployment Diagram (Image Created by Researchers)

CONCLUSION

ADDRESSING CRITERIA

(Icons from Flaticon)

- A strong classification, 0.98 AUROC Score demonstrates high proficiency when compared to traditional CNNs
- Extremely replicable, each buoy took <46 hours to print and assemble, and costs much less when compared to current market buoys
- MobyGlobal's performance is real-time, with minimal processing delay measured and low server latency.

APPLICATIONS

- The target application for this architecture is to **prevent whale injury and deaths** through the early detection of whale-dense areas. The aim is to reduce collision-related deaths and fishing net entanglement by rerouting ships or informing people of whale-dense areas.
- An extension is the use of our database, MobyGlobal, to contribute to the development of **marine data for any marine mammal with a distinct sound**. This can be used to strengthen conservation efforts by providing critical data.

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