Leveraging Machine Learning for Autonomous Ultrasonic Mitigation of Harmful Algal Blooms Along the Pacific Coast

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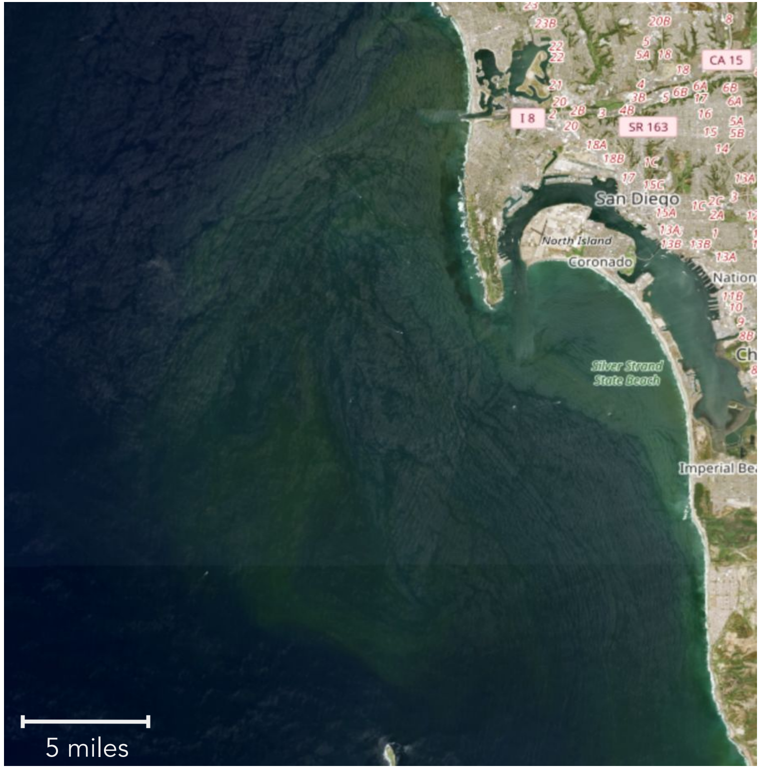
Harmful Algal Blooms (HABs)

- HABs are a growing environmental threat due to climate change.
- Causes ecological damage: fish kills, water quality degradation, toxin production.
- Economic impact: losses in aquaculture, tourism, and water-dependent industries (e.g., $800 million lost from a single bloom).
- Current methods of HAB management are often ineffective or environmentally harmful (e.g., chemical treatments).
- Oceanic HABs receive less attention than freshwater blooms but pose significant threats to marine ecosystems.

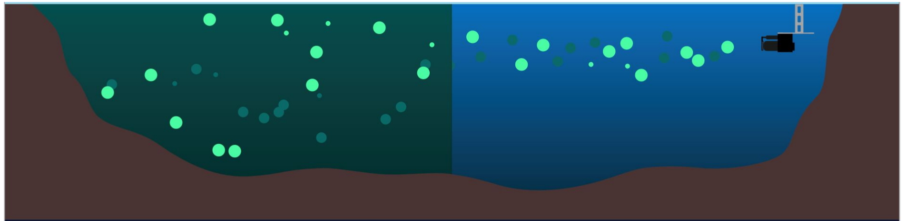


Literature Review: Machine Learning for HABs

- Machine Learning (ML) is increasingly used to predict and classify algal blooms.
- Studies focus on satellite imagery for detecting chlorophyll levels and algal presence.
- ML models (e.g., CNNs) used to identify algae based on environmental factors like temperature, water quality, and nutrient levels.
- Previous work primarily focused on forecasting blooms rather than active mitigation.

Literature Review: Ultrasonics for HABs

- Ultrasonics have been explored as a method to disrupt algal cells.
- Potential of cavitation to disrupt algal cells without chemicals.
- Different algae species respond to varying ultrasonic frequencies (20-100 kHz).
- Current studies focus on single-species disruption (e.g., Microcystis aeruginosa).
- Most ultrasonics research is limited to lab settings, with few field applications.



Without treatment	With treatment
Algae moves to the water surface for photosynthesis to grow, and to the bottom of the water column for nutrients.	Ultrasonic wave blocks algae's access to sunlight & nutrients. Algae sinks to the bottom and dies off without releasing toxins.

Research Objectives

- Develop a CNN-based model for classifying different HAB species using satellite imagery.
- Integrate ultrasonic mitigation technology to disrupt harmful algae based on species-specific frequencies.
- Propose a scalable, eco-friendly solution for large-scale, real-time HAB mitigation.
- Evaluate the performance and explore future improvements for larger-scale deployments.

Data Collection Locations

- Dataset: Collected satellite images of HABs along the Pacific Coast.
- Used data from CALHABMAP and HAEDAT databases, which provide genus-specific algal data.
- 8 locations from British Columbia to Southern California
- 8 different algal genera (e.g., Dictyota, Alexandrium).
- Temporal coverage: multiple years of blooms in each place (e.g., Ceratium: 2022-2023).

RECORDED GENERA AND BLOOM YEARS BY LOCATION.

Location	Genera	Collected Bloom Years
Clayoquot Sound	Chaetoceros, Dinophysis	2019
Georgia Strait	Dictyota	2018 - 2023
Del Norte coast	Alexandrium	2022, 2023
Bodega Bay	Pseudo-nitzschia	2021
Tomales Bay	Ceratium, Pseudo-nitzschia	2021
Richardson Bay	Heterosigma	2020 - 2022
Monterey Bay	Gymnodinium, Pseudo-nitzchia	2021
Ventura	Ceratium	2020, 2021

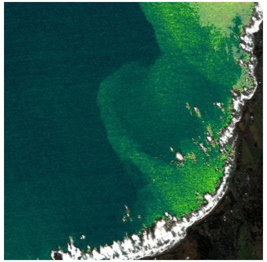
Dataset Satellite Image Filters

- True color images and Ulyssys Water Quality Viewer (UQWV) filtered images used for analysis
  - True Color Images: Show visible features like algae color and surface texture, aiding in basic identification.
  - UQWV Filtered Images: Enhance detection of water quality issues (e.g., chlorophyll, turbidity), improving algae and pollution analysis.
- Key challenge: Distinguishing chlorophyll content from sediment in satellite images.

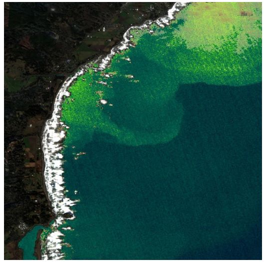
Data Augmentation

- Used Keras' ImageDataGenerator for generalization.
- Applied random rotations (up to 20°), shifts, and zooms (up to 20%).
- Horizontal flipping and shear applied to increase dataset variety.
- Augmentation was applied to both true color and filtered images.
- Final dataset: 4998 images from satellite observations.

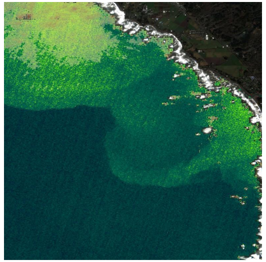
Original



Rotation



Reflection



Zoom

Machine Learning Architecture

- CNN architecture developed to process both true color and water quality filter images.
- Two parallel branches: one for visual features and one for environmental features.
- Convolutional layers with increasing depth (16, 64, 128 filters).
- Max Pooling and Global Average Pooling used to reduce dimensionality.

Machine Learning Architecture

- Features from both branches concatenated into a single vector.
- Fully connected layers with ReLU activation for final classification (64 and 32 neurons).
- Output: softmax layer predicts one of 8 algal genera.

Ultrasonic Frequencies

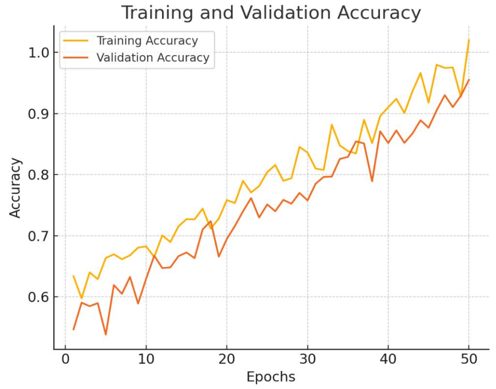
- Ultrasonic emissions range from 20 kHz to 100 kHz.
- These frequencies will not harm humans or other oceanic organisms
- Optimal frequency depends on algae cell wall composition (e.g., Alexandrium: 25-30 kHz).
- Lower frequencies (20-30 kHz) disrupt softer cell walls, while higher frequencies (50-100 kHz) target tougher walls.

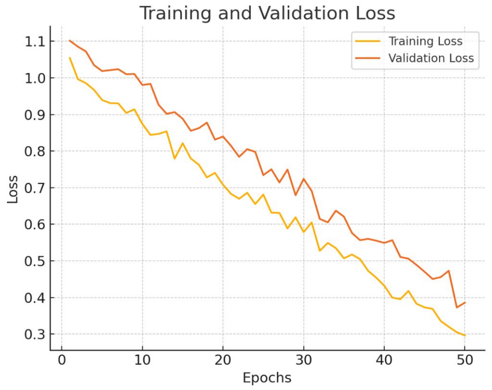
OPTIMAL FREQUENCIES BY GENUS.

Species	Effective Ultrasound Frequency (kHz)
Alexandrium	25-30
Ceratium	30-60
Psuedo-nitzschia	50-100
Gymnodinium	30-60
Dichtyocta	40-60
Chaetoceros	50-100
Dinophysis	30-50

Results

- CNN model achieved 98.2% accuracy in classifying 8 different algal genera.
- Data augmentation helped prevent overfitting and improve robustness.
- The model successfully distinguished between genera based on satellite and filter images.



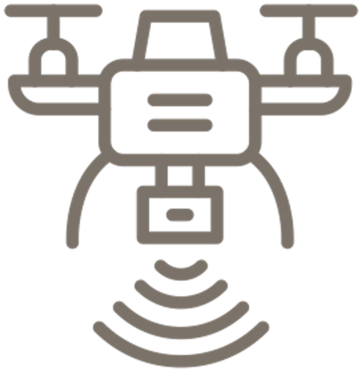


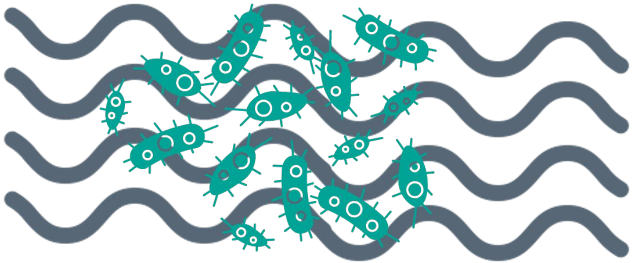
Hardware Integration Proposal

- Two-stage system: aerial drone for detection and floatation device for ultrasonic treatment.
- Drone captures high-resolution images and gathers environmental data.
- Underwater device emits algae-specific ultrasonic frequencies to neutralize HABs.
- Scalable and non-invasive solution for real-time algal bloom mitigation.

Hardware Integration Proposal

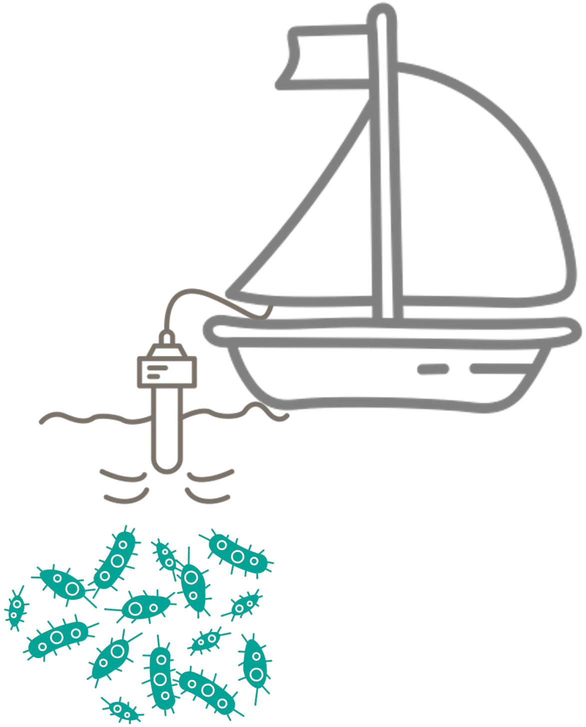
- Stage 1: aerial drone for detection and classification.
- Equipped with imaging sensors and environmental-scanning equipment.
- Collects high-resolution images and environmental data (e.g., water temperature, turbidity).
- CNN model classifies algae types based on collected images.
- The drone communicates optimal ultrasonic frequencies and GPS coordinates for treatment.





Hardware Integration Proposal

- Stage 2: underwater device for ultrasonic treatment.
- Uses ultrasonic transducers to emit algae-specific frequencies at the detected GPS locations.
- The transducers create cavitation bubbles to break down algal cells without chemicals.
- Advantages of the system:
  - Real-time detection and treatment.
  - Non-invasive and eco-friendly solution.
  - Scalable design for large water bodies like oceans.



Conclusion

- Machine learning and ultrasonic technology provide an innovative, eco-friendly approach to HAB mitigation.
- Genus-specific treatment ensures minimal environmental disruption.
- Model's high accuracy and scalable hardware integration showcase the potential for large-scale application.
- Future work: expanding to other algal species and improving system robustness.

Thank you!