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

Sajeev Magesh
Dublin High School
Dublin, California, USA
sajeevmagesh123@gmail.com

Varun Rao
Mission San Jose High School
Fremont, California, USA
varrao23@gmail.com

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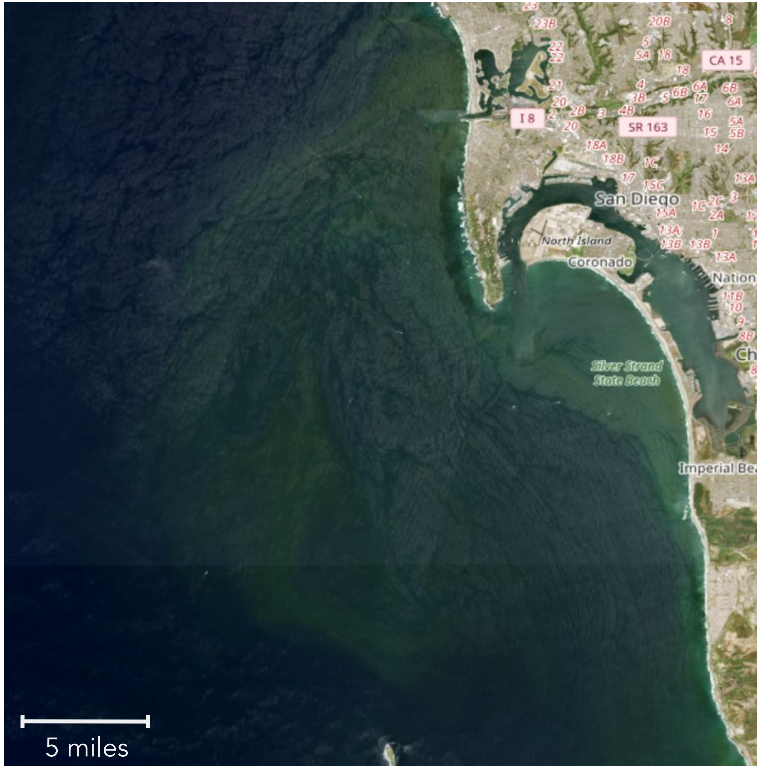
Harmful Algal Blooms (HABs)

- 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.

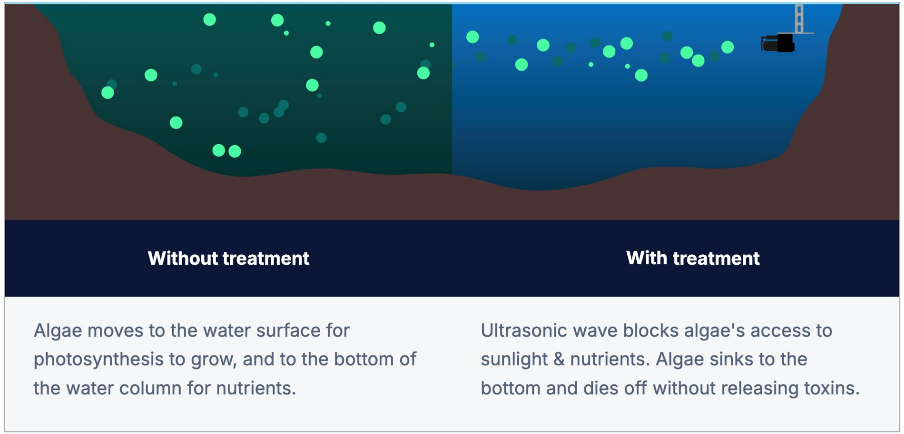


Literature Review: Machine Learning for HABs

- 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: Ultrasound for HABs

- Ultrasound has 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 ultrasonic research is limited to lab settings, with few field applications.



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

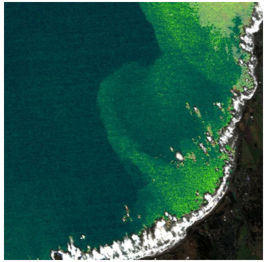
Dataset Satellite Image Filters

- 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.

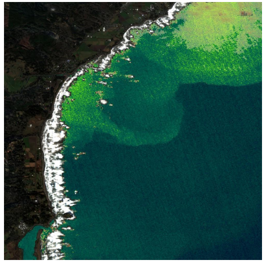
Data Augmentation

- 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.

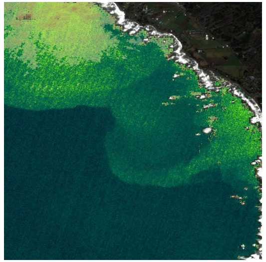
Original



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

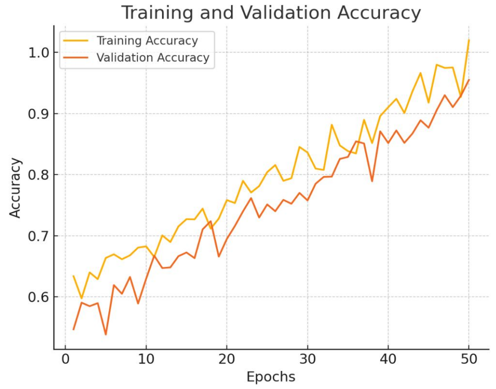
- Ultrasonic emissions range from 20 kHz to 100 kHz.
- These frequencies will not harm humans or other oceanic organisms
- Optimal frequency depends on algae cell wall composition (e.g., Alexandrium: 25-30 kHz).
- Lower frequencies (20-30 kHz) disrupt softer cell walls, while higher frequencies (50-100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

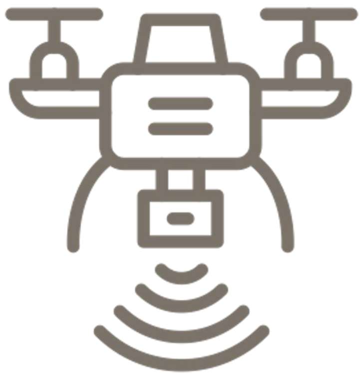


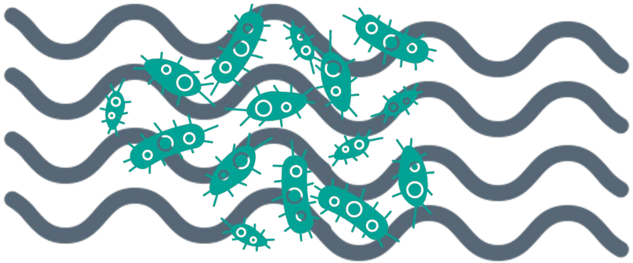
Hardware Integration Proposal

- 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

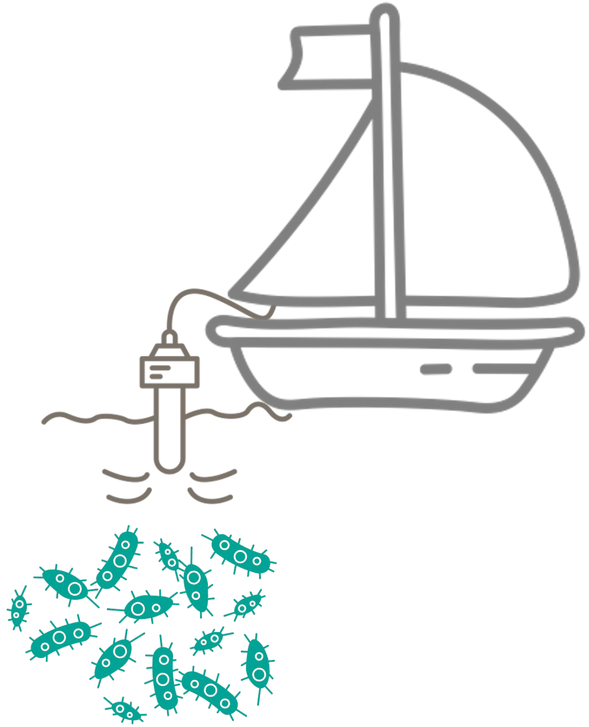
- Stage 1: aerial drone for detection and classification.
- Equipped with imaging sensors and environmental-scanning equipment.
- Collects high-resolution images and environmental data (e.g., water temperature, turbidity).
- CNN model classifies algae types based on collected images.
- The drone communicates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





Hardware Integration Proposal

- Stage 2: floatation 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!