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得獎獎項　三等獎

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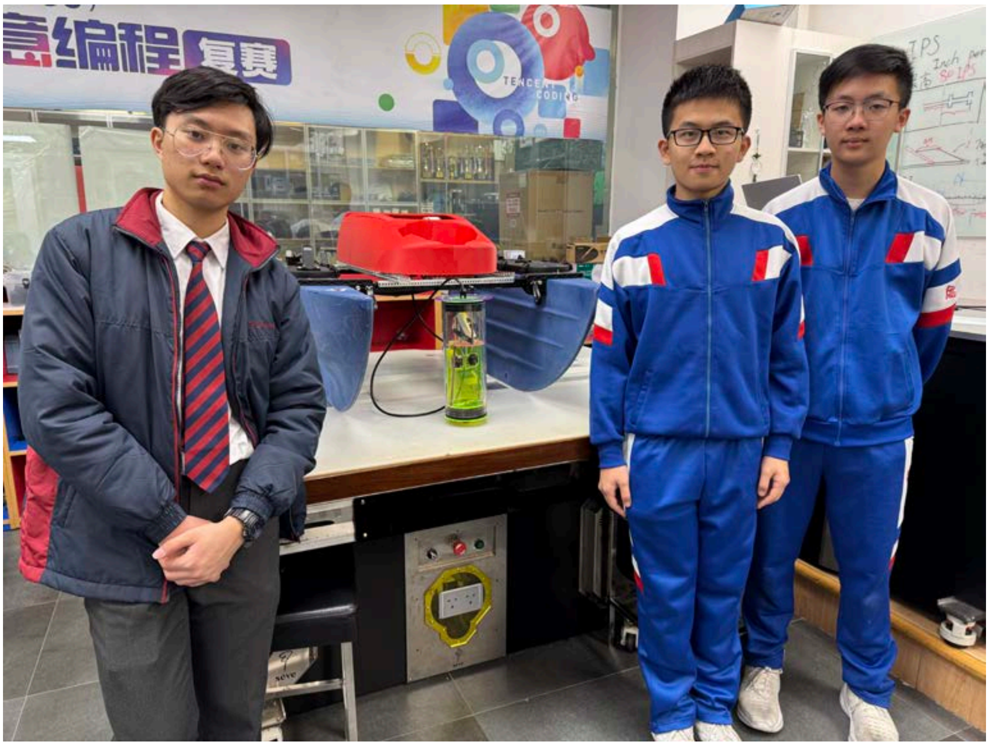

Technical Report on

Autonomous Ecosystem Surveillance Vehicle

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Project Team

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Table of Contents

Background

As of 2021, there are 368 harmful algae blooms and over 6000 invasive species in the United States of America. Furthermore, it is reported that the United States spends more than 11.1 billion dollars per year on clean-up methods for marine debris. However, there currently isn’t a method to monitor aquatic problems simultaneously, autonomously, and efficiently, creating a capability in the aquatic biosecurity sector. To combat this, we have created an autonomous vehicle that can conduct long-term monitoring of freshwater bodies for up to 60 hours.

A. Water Quality Monitoring

Freshwater lakes such as Lake Erie in the USA and Lake Tai in China have been experiencing the emergence of "dead zones" caused by excess nitrate in the past decade. Nitrate promotes the growth of algae, during which the algae proliferate rapidly, forming dense populations. As the algae eventually die and decompose, bacteria and other microorganisms break down the organic matter, consuming dissolved oxygen. The combination of increased microbial activity and the sheer biomass of the algae depletes oxygen levels in the water, resulting in adverse impacts on marine life, including fish mortality.

Fig. 2 Noctiluca scintillans bloom. Coloane, Macau

Fig. 3 Discharging untreated sewage causes pollution.

Moreover, reservoirs, where algae commonly exist, are used to store drinking water, meaning that an algal bloom will harm the area's citizens. While there are methods of killing these algae in reservoirs, such as chemicals like algaecides, which may be successful in eliminating algae and harmful substances, the usage of these chemicals will simply hinder the purification process of water, leading to a higher cost to produce drinking water.

Fig. 4 Algae bloom on the Sassafras River. Fig. 5 Harmful Algal Bloom

For scientists to transport water samples back to laboratories for testing, a massive amount of time will be consumed, leading to inaccurate results as the aquatic environment is an ever-changing one. Furthermore, This method cannot get data in real time over an extended period, meaning we cannot accurately predict the possibility of an algal bloom as the time differences between data are inconsistent and too long.

To address this environmental challenge, our team has developed an innovative boat capable of monitoring and predicting algal blooms in bodies of water. By leveraging the Beer-Lambert Law and deep learning techniques, our boat analyses water samples to find nitrate levels. This enables the boat to provide valuable insight and predictions regarding algal blooms' likelihood and potential locations, assisting in proactive management and mitigation efforts. Lastly, by applying regression models and combining weather data with the nitrate levels, the boat can predict and output a heatmap on the estimated locations for algal blooms to occur.

B. Aquatic Species Monitoring

Recognizing the additional threat posed by invasive species to water bodies, our team has also integrated a function within our boat to detect invasive species. Current methods to achieve this mainly rely on the human eye and passersby spotting to find invasive species in lakes or reservoirs, which is heavily unreliable, as passersby might not know who to contact or whether the fish is invasive.

To combat this, we created a system that employs advanced data analysis and, pattern recognition, and similarity comparison algorithms to identify the presence of invasive species in aquatic environments. By combining the frequencies at which an invasive species appears, we can output another heatmap of the species densities and estimate the population of the invasive species. This information can then be forwarded to a generative AI, advising officials on removing these species.

Fig. 6 Sample Heat Map

C. Water Environment Monitoring

Lastly, our team decided that litter detection would be the central aspect of research and usage in monitoring water environments. Traditional methods of detecting and removing litter from water bodies often rely on manual inspections, which can be time-consuming and inefficient.

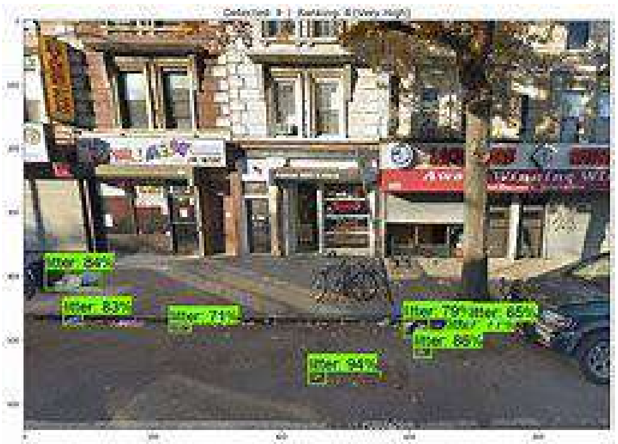


Fig. 7 Litter Detection Implementation On Land

Integrating data analysis and machine learning techniques, the on-boat computer can generate real-time maps or reports indicating the locations and densities of detected litter. This information can then be shared with relevant authorities and environmental organizations, enabling them to prioritize and efficiently allocate resources for litter removal and prevention efforts.

In summary, our all-round aquatic environment surveillance boat addresses the deteriorating water quality in lakes and reservoirs by monitoring and mitigating harmful factors such as nitrate levels, invasive species, and litter. By utilizing advanced technologies like deep learning and data analysis, the on-boat computer predicts and detects algal blooms, identifies invasive species, and detects and maps litter in real time. This enables proactive management and intervention efforts, leading to improved water quality, enhanced ecosystem preservation, and the protection of aquatic life.

Engineering Goals

Chemical treatments can have unintended consequences on the aquatic environment. Algaecides, for example, can harm not only the target algae but also other non-target organisms such as fish, invertebrates, and beneficial algae species. Similarly, the use of nitrate-reducing agents can alter the natural nitrogen cycle and disrupt the balance of the ecosystem.

Frequent and repeated use of chemical treatments can lead to the development of resistance in target organisms. Algae, for instance, can evolve and become resistant to certain algaecides over time. This can result in the need for more robust or potent chemicals, leading to a continuous cycle of escalating chemical use.

To solve the problems as mentioned above, our team created a sampling system capable of collecting water samples from most depths. This project aims to monitor bodies of water frequently by collecting water quality data from local reservoirs and to provide researchers and local authorities with swift and accurate water quality data to prevent disasters. We have compiled a list of potential goals to develop:

1. Able to collect water quality data from most depths
2. Ability to be autonomous
3. Live water quality data (pH, dissolved oxygen, nutrients, metals, hydrocarbons, industrial chemicals)
4. Deep learning towards prediction of algae blooms
5. Conservation of biodiversity
6. Analyzation of underwater environment

Improvements

Due to this being a continuation project, we have received suggestions as well as thought about some inadequacies of our project:

1. **Environmental Limitations**: Performance may be affected by water depth, clarity, and environmental conditions, potentially limiting effectiveness.
2. **Limited Range of detection**: The spectrometer may lack the required detection range to estimate the possibility of a dead zone properly.
3. **Limited Range**: Although designed for autonomy, the vehicle may have operational limitations regarding distance from the shore and battery life.

In response to the comments and suggestions our team received last year regarding our project, we have made some adjustments accordingly. The most visible improvement from the previous design was the inclusion of the BlueRobotics BlueBoat, which gives the vehicle much more flexibility in the areas it can be deployed as it can be folded up and transported in a car, in contrast with the old design where a minivan or a flatbed truck was required.

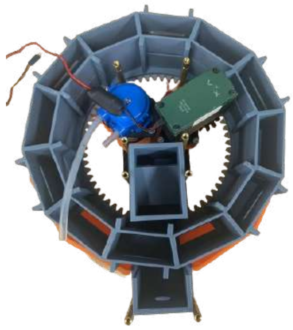
Fig 8. Improved design and platform

A new design for the vehicle's surveillance system has been developed alongside the new platform. We split the system into three parts: the spectrometer in the very front, the tether roller for the lowering platform in the middle, and other electronics in the back. This reduces the possibility that the systems will be mixed while still allowing strong integration between the systems.

Due to the limitations and uncertainties of the existing invasive species detection model, we have opted to adopt a novel approach to enhance our detection capabilities. The murkiness of water and the lack of measures to combat this in our previous iteration was a major flaw leading to a massive drop in efficacy. Thus, we have developed a three-step procedure that removes this issue.

Firstly, Google's google-maxim-s2-enhancement-lol model is used to improve the brightness of the footage given, which removes the fuzziness from the footage. Then, convolution techniques are applied to the clear footage to sharpen and enhance it. Instead of using an object detection model as previously done, we have decided to use the API of Gemini-1.5-Flash to identify various invasive species.

Additionally, the spectrometer can now detect various chemicals that are beneficial to the early warning system of dead zones. We expanded the program to include calculations that estimate the concentration of chemicals such as phosphorus. As a whole, the material of the spectrometer has been replaced with 3D printed material, giving it a stronger platform and allowing for the rapid construction of the spectrometer due to the increased simplicity of the design.



To further enhance the accuracy and reliability of our invasive species detection system, we have integrated the BeiDou Navigation Satellite System. This advanced satellite navigation system provides precise positioning data, which is crucial for accurately tracking the locations of the underwater footage being analyzed. By utilizing BeiDou, we can ensure that our detection efforts are geographically precise, allowing us to correlate the presence of invasive species with specific environmental factors and locations. This integration not only improves real-time monitoring capabilities but also aids in the long-term analysis of invasive species trends, ultimately contributing to more effective management and conservation strategies in aquatic ecosystems.

3. Design

3.1 Main Hull

I. Generation One Design

In the beginning of the development of our boat, we created a prototype boat only capable of moving. As shown on the image below, the boat was only equipped with a computing unit on top. This design allowed the boat to be controlled wirelessly, but lacked other features such as a lowering platform for better data collection, a camera to monitor the ecosystems etc…

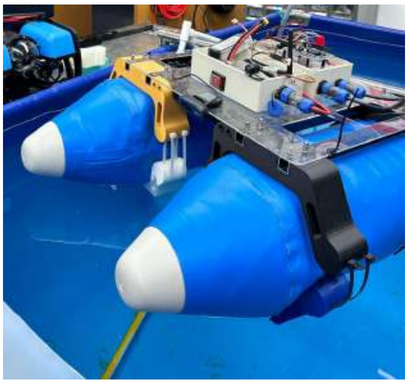


Fig.1 Initial design of the boat

II. Generation Two Design

After building the first design, we turned our hardware focus to specific task-related features. This included a lowering platform equipped with cameras to monitor the water at different depths, a new rotating platform for obtaining nitrate data on top, and a better battery system for the boat.

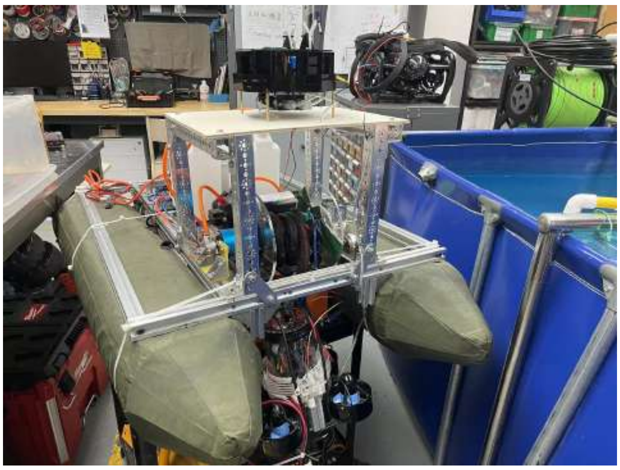


Fig. 2 Second design of the boat

III. Generation Three Design

Lastly, in our current generation, we have utilized a commercial Blueboat as the main hull for our vehicle to speed up the development process. The main hull possesses a more accurate navigation system, allowing for long-term monitoring. The hull also allows for the vehicle to reach higher top speeds, with the following specifics.

Specs	Value
Battery Time	~62 hr
Width	36.5 in
Length	48 in
Max Speed	3 m/s
Thrust	8.2 kgf
Payload	15 kg
Voltage	12 V

Fig. 3 Specific information on current generation

Fig. 4 Current generation design

3.2 Lowering Platform

To obtain information from different depths, we have engineered a lowering platform that is able to extend up to 20 metres into the water to obtain water samples and images. Furthermore, we have integrated two cameras facing opposite sides to survey the surrounding completely, and miscellaneous sensors such as pH, oxygen content, water temperature, and conductivity sensors.

Fig. 5 Lowering Platform

Fig. 5.1 Miscellaneous Sensor Data

3.3 Spectrometer

Collecting samples is a mainstay in this project, therefore our team has deliberated many times on the methods to do rapid water quality tests and how to clean the equipment that has touched the water.

The design first started off as a singular spectrometer based on the Beer-Lambert Law, where the cuvette had to be cleaned every time to ensure cross contamination was not an issue. This design includes a 3D printed sample holder with an LED to illuminate the two cuvettes, as well as a mirror to reflect the spectra onto the hole on top.

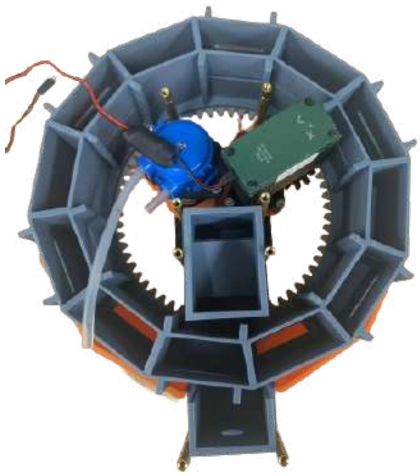


Fig. 6 Inside the sample holder

We then moved on to automatic cuvette cleaning, but that solution was too mechanically complicated and tedious, as well as concerns that this system may not clean very adequately, which led us to the revolving cuvette system.

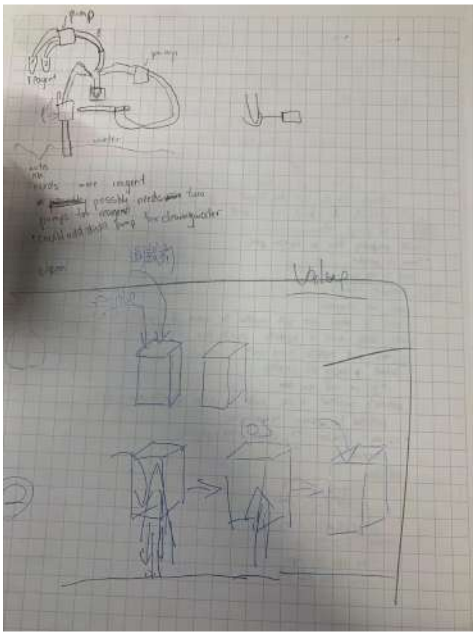
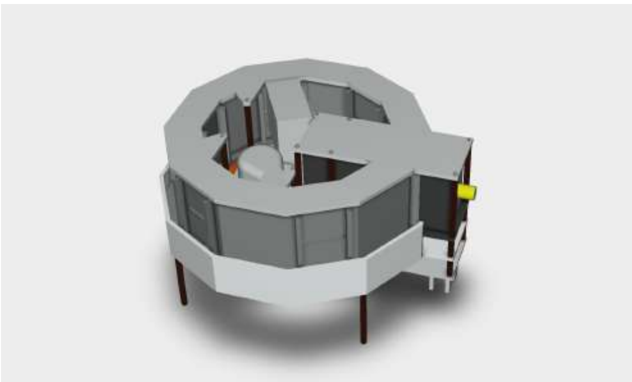


Fig. 7 Rough drawing of automatic cuvette cleaning

It was first designed to be linear, but after space considerations and being able to expand the system much more efficiently, we opted for a circular design at the end.



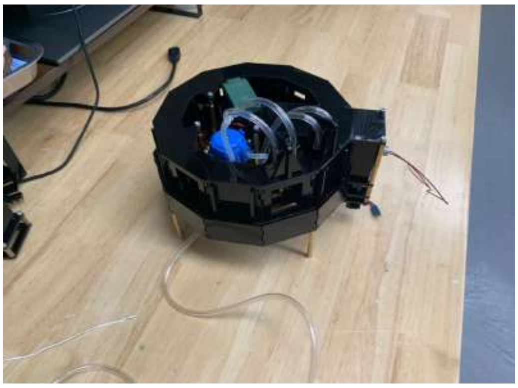


Fig. 8 3D model multi-sampling spectrometer

Fig. 9 Spectrometer

4. Innovation and Functionality

4.1. Nitrate Surveillance

The boat detects nitrate concentration using the Beer-Lambert Law, where the light absorbed illustrates an equivalence with nitrate concentration in the water. After running calculations, the minicomputer onboard will log down the nitrate concentration in that particular place via gps positioning. As this data is collected in real time, water samples do not need to be brought on shore for more thorough analysis.

Our spectrometer uses colorimetry to perform detection on nitrate. This spectrometer was built based on the Beer-Lambert law. Firstly, the water absorbs the reagent, and then the water will change its color depending on the amount of nitrate it has in the water. Then the light inside the spectrometer will turn on, and the light will shine through a hole in the sample holder. Depending on the amount of nitrate in the sample water, some light may be absorbed by the sample. The light then goes through another slit and into a mirror, reflecting up into a hole in the spectrometer. The user can now take a photo of the spectra and directly send the image into the python code. Calibration is needed for the spectrometer to work correctly; otherwise, there is little to no preparation required for said program to function

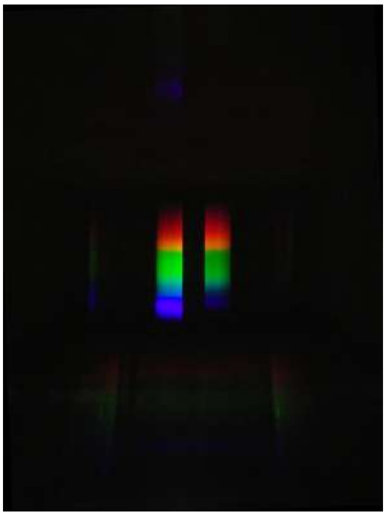


Fig. 10 Spectra returned

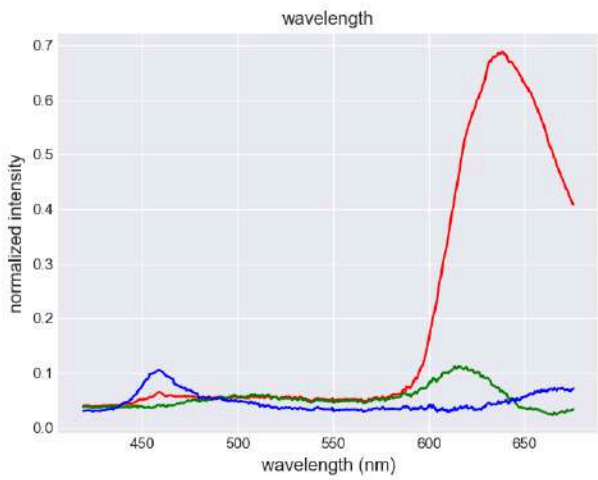


Fig. 11 Wavelength Analysis

Our team has designed a revolving sample machine that bestows the boat with the ability to analyze several locations at once. This works via rotating a set of cuvettes through a system. In the center is a robotic arm that will pick up samples from the water beneath it, and put the samples into position. Then, a camera will take a photo of the spectra and upload the photo to the computer, which will then output the nitrate intensity. In the future the ability to clean them during an outing may be installed. The revolving system was made to be circular due to the limited amount of space onboard the boat, and this system allows for easy access into the chamber.

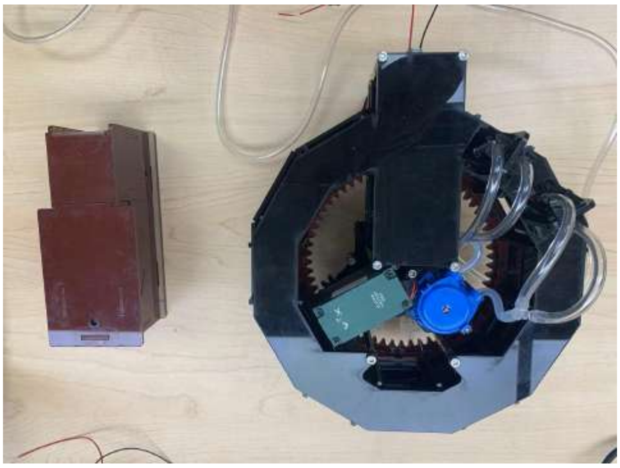
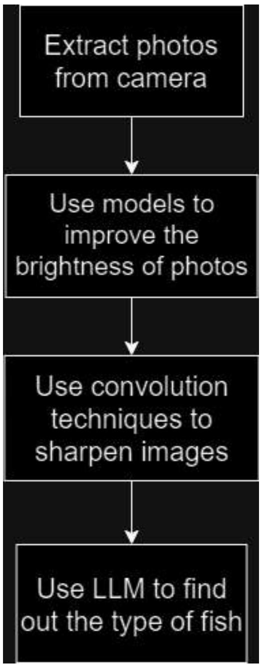


Fig. 12 Original spectrometer (left) and the revolving system (right)

Following an extended term of data collection, it may be able to predict long-term health of a certain body of water, such as when algae blooms will happen, using long short-term memory neural networks.

4.2. Invasive Species Monitoring

Our monitoring can mainly be divided into 4 parts. We start the procedure using an underwater robotic device to capture fish images. The **google-maxim-s2-enhancement-lol model (MAXIM model)** is then used to apply a brightness improvement process to the acquired photos, greatly increasing their visibility and clarity. After improvement, we sharpened the pictures using neural approaches to ensure they were optimal for precise detection. To determine if the fish pictured are invasive, the last stage is using the **Gemini-1.5-Flash API** for species identification. This is an essential part of ecological surveillance and protection.



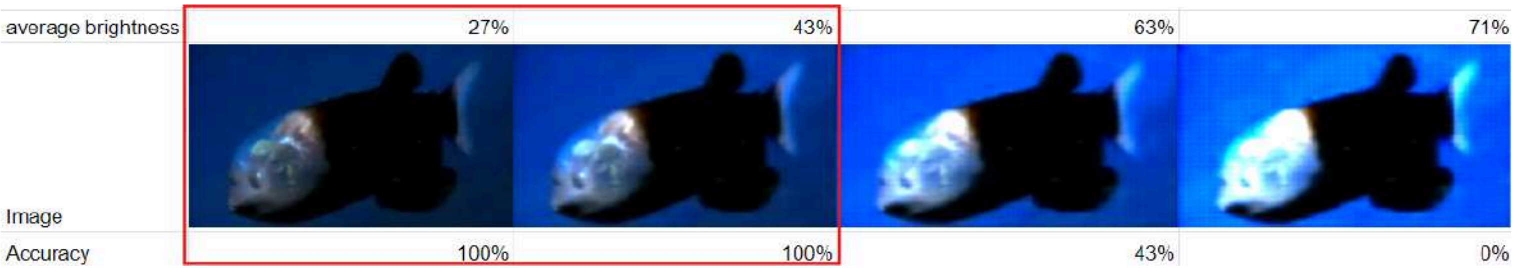
Steps to test invasive species detection

I. Using the model to improve the brightness

We use the lowering platform's camera to record footage underwater to detect possible instances of invasive species. However, the footage tends to be unusable due to the low brightness and the murkiness of debris underwater.

Example of low-brightness footage: barreleye fish

To solve this problem, we decided to brighten and clarify the retrieved photographs using the **google-maxim-s2-enhancement-lol model (MAXIM model)**. This procedure can enhance the photographs' visual quality and provide a strong basis for the upcoming fish identification work about LLM. The results are as follows:

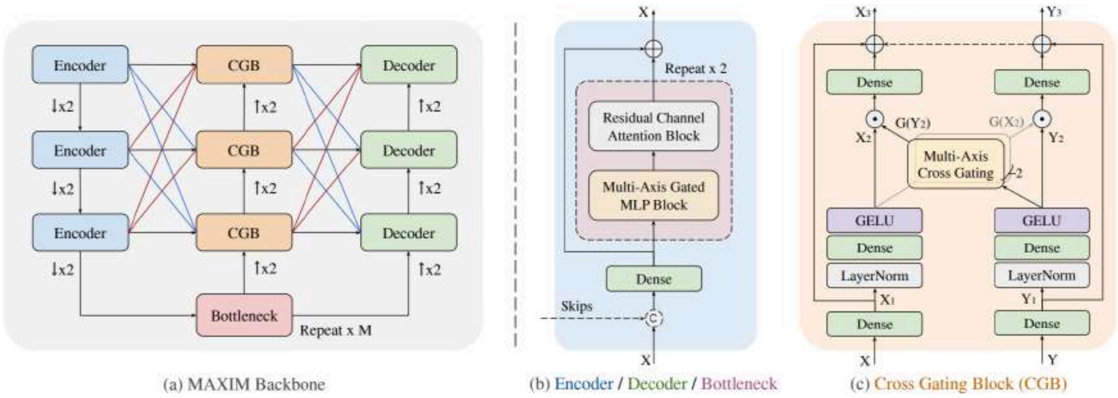


MAXIM results

As you can see, when the image's average brightness is between 20% and 40%, LLM provides the most accurate result. As a result, we will use these figures as our starting point when assessing a photo's brightness.

MAXIM results of other photos Top: Original photo; Bottom: cleared photo

Since the real environment is complex and variable, the use of models can effectively cope with the different brightness distribution of the picture. If the brightness of the whole picture is only increased by one, some of the already high brightness areas of the original picture may lead to exposure problems, which can be avoided by using the model.

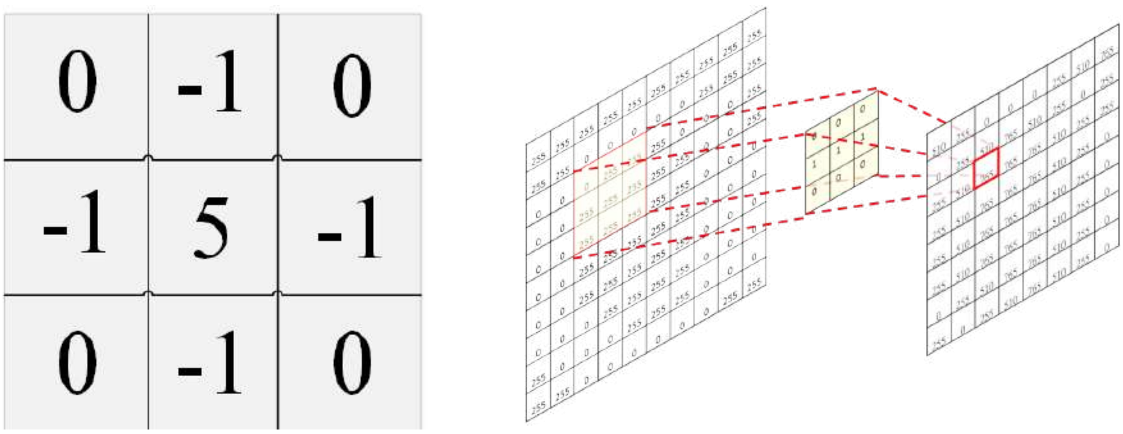


The structure of the **MAXIM model**

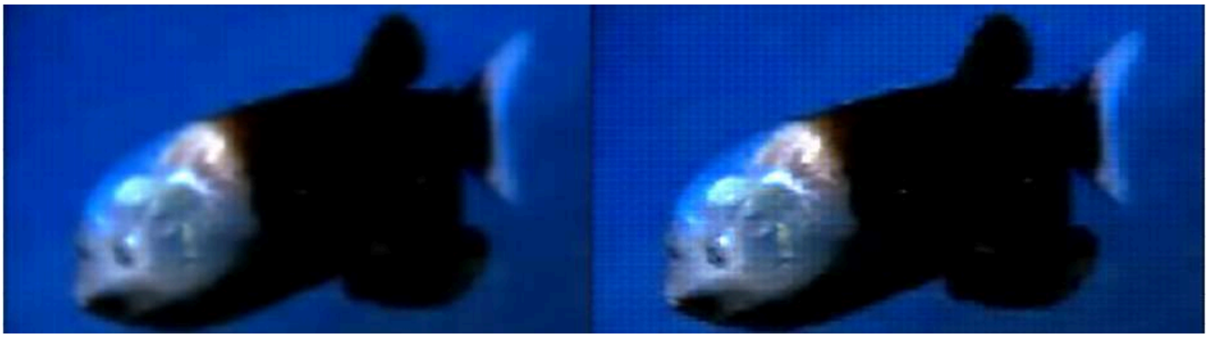
II. Image sharpening

Nevertheless, there may occasionally be negative impacts following the model brightening procedure, such as the image becoming hazy. We must sharpen the image much further in order to solve this problem.

To increase the accuracy and dependability of LLM in recognizing fish species, we decided to apply convolution in this procedure to sharpen the image and re-highlight the already-blurred characteristics.



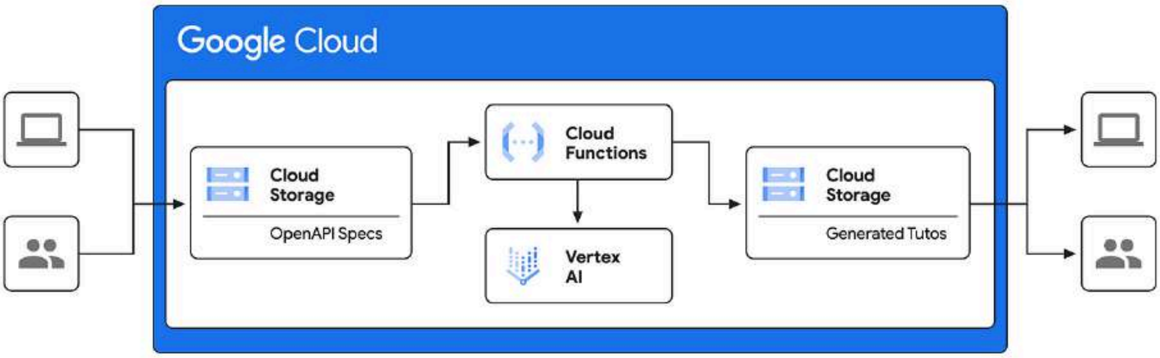
Left: The sharpening convolution kernel we use. Right: Convolution representation diagram



Left: Pictures that have been brightened. Right: Pictures that have been both brightened and sharpened

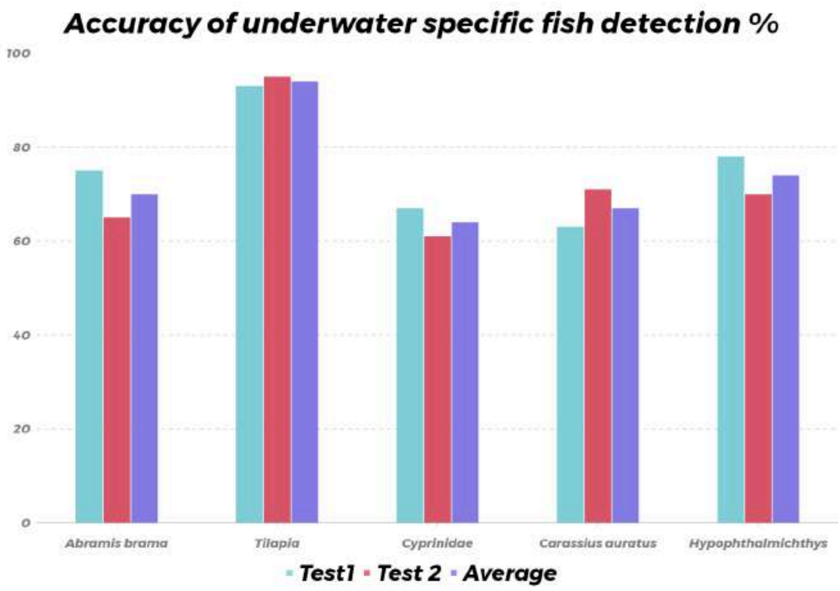
III. Using Gemini for Underwater Invasive Species Identification and Fish Image Recognition

The last step is to identify underwater invasive species and boost the identification of unique fish photos. YOLOv8, which could classify fish's head, tail, and body components, was replaced with the most recent **Gemini-1.5-Flash** AI model, a Large Language Model (LLM).



Steps on using **Gemini-1.5-Flash** AI model

As opposed to YOLOv8, which needs a large quantity of particular photos in order to do deep learning, **Gemini-1.5-Flash** accepts multimodal input, which allows it to process image material that is more complicated while also improving recognition accuracy. We locally use the Gemini-1.5-Flash API to identify fish species after taking underwater photos. The Tilapia, Cyprinidae, Carassius auratus, and Hypophthalmichthys are common fish species found in Macau ponds that the method is intended to identify. Fish that are not included in this list will be classified as invasive species.



Detection accuracy of various types of invasive species

Dataset of the 5 sample fish species.

The result returned by LLM

4.3. Litter Monitoring

For the dataset of litter detection, 250 images of underwater imagery were used. In these 250 images, 40 images were marked null, which indicated that there was no litter in these images.

Similar to the previous functions, YOLOv8 was also used to detect litter. First, the images were preprocessed and shrunk into a 640 x 640 size image. Next, the photos were trained for 130 epochs.

After identifying trash, our robot will take note of its current location and the amount of trash detected. This will then be sent to a local database, which will use this information to output a real-time heatmap.

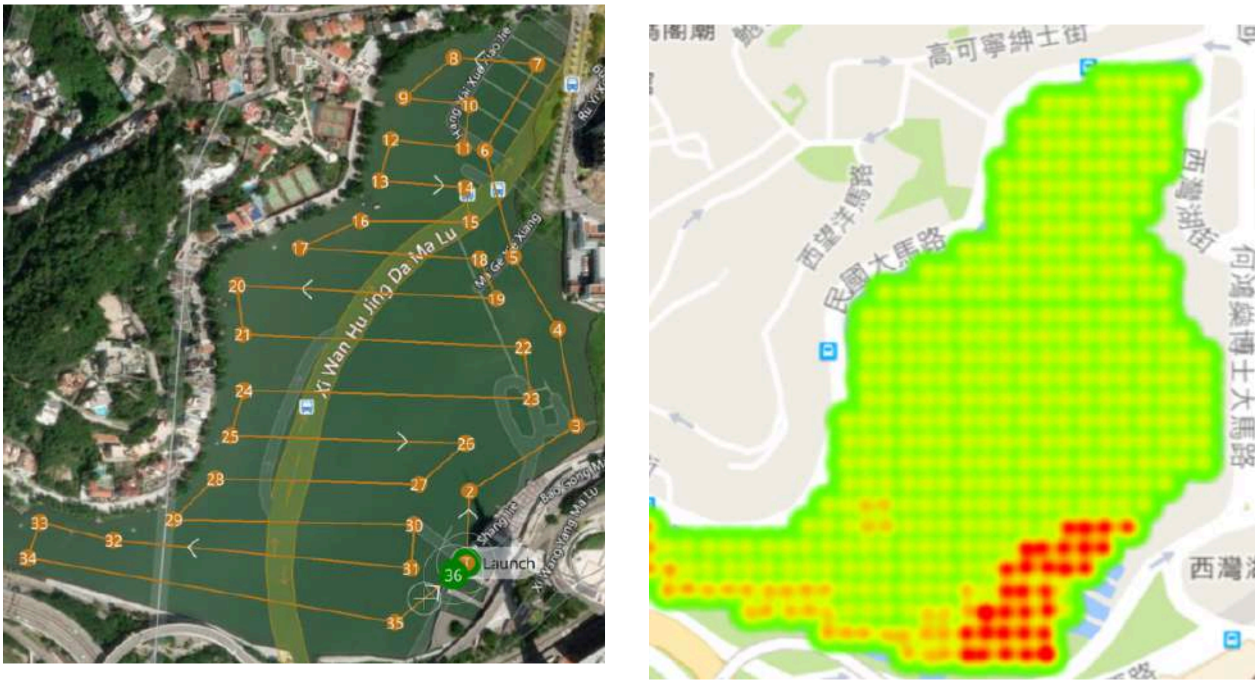


Fig. 14 GPS Map vs Heat Map

4.4. Monitoring System with Unmanned Boat

The unmanned boat, acting as the carrier, is equipped with navigation and control systems and can autonomously plan and navigate a pre-set route to designated waypoints while avoiding obstacles and adapting to changing environmental conditions. This autonomous planning allows the boat to efficiently and safely navigate to its intended waypoints.

Once the unmanned boat reaches designated waypoints, it notifies the monitoring system of its arrival so that the system can activate various operations.

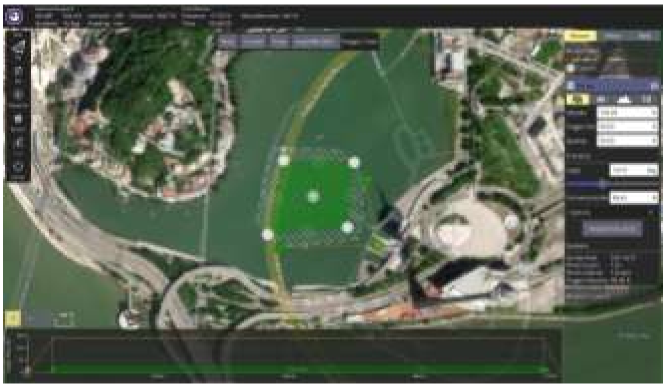


Fig. 15 Navigation and path

The two common modes:

1. Routine patrol mode: Capable of periodically monitoring at specific waypoints to ensure that the water quality remains at a stable level. Provides a systematic and proactive approach to surveillance and maintain water quality, allowing for timely interventions and the preservation of a stable and healthy aquatic environment.
2. Event-triggered monitoring: It allows for targeted data collection when specific ecological events occur, and has entered a more severe situation that requires round-the-clock real-time monitoring. Provide high-density, long-lasting sampling and analysis conducted at specific locations. This continuous monitoring aims to surveillance the situation and identify the underlying causes.

Also provide real-time data transmission, after collecting and analyzing samples. The unmanned boat can transmit the data back to the monitoring system in real-time. This enables prompt analysis and decision-making based on the collected data.

One of the key features is its Environmental Possibility Prediction Based on Intelligent Analysis. By analyzing previously collected dataset and its relationship with overall environmental events, we can provide opportunities and buy time for early prevention. This approach involves collecting and analyzing large volumes of data from various sources, including environmental sensors and historical records.

Using advanced analytics techniques, such as machine learning and data mining, to identify patterns, correlations, and anomalies. By uncovering these insights, we can gain a better understanding of the relationship between different environmental factors and events.

5. Experimentation

5.1 Depth testing

We have tested the vehicle's capabilities in different depths. This test led us to find that due to brightness differences caused by the different depths, the vehicles testing capabilities became decreasingly accurate the deeper the platform was. We hope to improve on this in the future by attaching a light atop of the platform to offer clearer images.

Fig.16 Testing images from different depths

Fig. 17 Image taken of fish on the seabed.

5.2 Location testing

We have tested the vehicle's capabilities in different locations to see if location affects the testing capabilities. We tested in an in-lab pool, an outdoor pool, and a local lake.

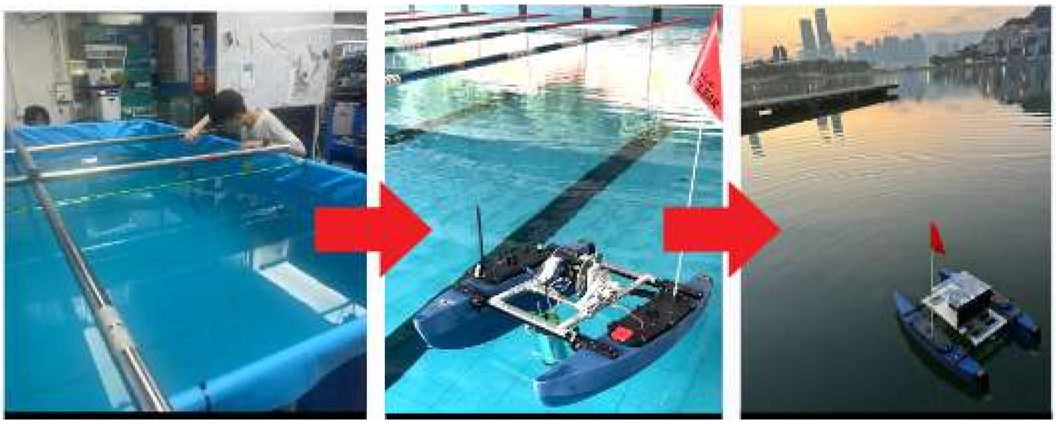


Fig. 18 Testing in different locations

We were able to conclude that the location did not hinder the testing capabilities.

6. Conclusion

Currently, biosecurity measures are in great need around the world. More specifically, aquatic biosecurity measures are suffering from an extreme capability cap between needs and actual capability. Issues such as harmful algae blooms like Lake Erie and Lake Taihu have proven such a need for more powerful biosecurity measures, as well as invasive species as the Asian carp, which poses a threat to the local food chain and the 7 billion USD per annum fishing industry. Powerful yet harmful chemicals may be used to combat these algae blooms when growth has gone out of control.

Therefore, our team has designed an Autonomous Ecosystem Surveillance Vehicle, or AESV for short, to inspect rivers, lakes, and other bodies of water for possible areas at risk of developing eutrophication and other harmful natural phenomena. This is done via a multiple sampling rapid nitrate spectrometer, an AI model that scans the surroundings for potentially invasive species, and a model that surveys the seabed for garbage and other large polluting materials.

Ref

1. Portable low-cost open-source wireless spectrophotometer for fast and reliable measurements
2. (PDF) Wind Effects for Floating Algae Dynamics in Eutrophic Lakes (researchgate.net)
3. https://github.com/xinzhichao/underwater_datasets Underwater Trash Dataset used in Detecting Litter Jungseok Hong, Michael Fulton, Junaed Sattar [Related Paper: https://arxiv.org/abs/2007.08097]
4. MAXIM pre-trained on LOL for image enhancement
5. Gemini API

【評語】100053

1. The topic suits green earth and humanity's needs. Yet, it is ambitious in terms of scope and coverage. Please highlight the advances that have been made in the project.
2. In addition to describing the engineering process of this research work and some survey of other works, it would be good (also required) to present the innovation of this work. A comparison of the proposed system with existing state-of-the-art methods should be provided in the introduction so the advances, contributions, and novelty of the approach can be identified.
3. Please also provide the overall architecture.
4. Including more field test results to consolidate the proposed idea would be good.
5. Some other technical questions:
   a. For nitrate surveillance, the protocol adopted was unclear. Nitrate does not absorb visible light, and some chemical kits would be required to react with nitrate before colorimetric analysis. It is unclear how this was automated. If no other chemical was used, nitrate was often measured by comparing the absorption at 220 nm (nitrate and organics) and 275 nm (organics). However,

the system does not appear to be capable of functioning in this UV range.

b. In Figure 11 “Wavelength Analysis,” it is unclear whether the Y-axis represents absorption, transmission, or raw CCD intensity. Additionally, the interpretation of the curves is ambiguous.

c. In the colorimetric analysis, how can the effect of light scattering caused by suspensions in the water be accounted for?

d. The authors are advised to employ the electrochemical method with ion-selective electrodes to measure nitrate levels.

e. In the current design, the authors mention the integration of "miscellaneous sensors such as pH, oxygen content, water temperature, and conductivity sensors" in section 3.2 "lowering platform." Enhancing the clarity of the presentation by overlaying heat maps or contour lines from each sensor onto the geological map is recommended to illustrate the functionality of this design. While Figure 14 provides a heat map, it lacks a clear explanation of the data displayed. The authors should include an accompanying look-up table to describe the color code and its corresponding values and units.