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Cleaning up the Coasts

A System for the Removal of Marine Microplastics Using Semi-Autonomous Vehicles

**Names are listed in alphabetical order by surname. All authors contributed equally to this project.*

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Abstract

In recent years, microplastic pollution has become an increasingly threatening problem for ocean ecosystems. With only 9% of plastics being successfully recycled, many end up in oceans where they break down into small particles less than 5 millimeters in length known as microplastics. These microplastics pose a threat to ocean wildlife, as many sea creatures are harmed by accidentally consuming them. Microplastics also end up contaminating human water and food supply. This report presents a system with the goal of identifying and collecting microplastics near coastlines in order to reduce the number of microplastics in the ocean that pose a threat to wildlife. The system consists of a combination of air and sea drones to locate and collect the microplastics, as well as charging stations to allow the drones to operate for extended periods of time. If implemented, this system will help combat microplastic pollution in oceans by preventing plastics from leaving the coastlines and going deeper where they could harm wildlife.

Introduction

Background

Ocean pollution has become an increasingly threatening problem in recent decades. There are estimated to be 5.25 trillion pieces of plastic in the ocean with 8 million tons of plastic being added each year [1]. Since the production of plastic accelerated after World War II, an increase in throw-away culture has also led to a dramatic increase in plastic pollution. For instance, in the past two decades, the rate of plastic pollution has doubled with only 9% of plastics being successfully recycled. The problem with plastics is that they don’t dissolve as other materials do in the ocean. This means that as more plastics enter the ocean, there’s no way to remove them unless they’re collected by something. Areas such as the Great Pacific Garbage Patch in the Pacific Ocean have been a problem, being a 1.6 million square kilometer area where plastic trash flows [2]. Often made up of many different types of plastics, microplastics have shown particular issues not only in the garbage patch but all around the world. Microplastics, plastics less than 5 mm in length, are found in every part of the world but especially in oceans where macroplastics are broken down into microplastics, finding their way into human water systems and harming ecosystems in the ocean. These plastics harm sea creatures tremendously with many animals being killed by accidentally eating microplastics and macroplastics leading to strangulation. It is estimated that more than 100,000 sea creatures die from marine plastic pollution each year. This not only damages ecosystems but also harms human food supplies [3].

Current solutions to relieving marine pollution include ocean cleanup efforts, government laws such as the Clean Water Act of 1972, and increasing the use of plastic-free alternatives to products. Particularly, ocean cleanup efforts have been attempting to challenge the massive pollution already in the ocean that other solutions cannot deal with. For instance, the Ocean Cleanup project [4] uses computational modeling and massive nets to clean up areas such as the Great Pacific Garbage Patch. Other freshwater solutions include using a boat to intercept plastics flowing through rivers [4]. However, the major problem with these solutions is the use of manpower to get them done. They require expensive equipment that needs to be managed by a lot of people to work effectively. This is why the use of automated technology to both find and collect plastics could be beneficial. Unmanned technology could allow for pollutants to be collected more efficiently and in areas that humans cannot access. Using Unmanned Aerial Vehicles (UAVs) would be a solution to monitor ocean conditions and plastics with little human interaction and accuracy. This in combination with Unmanned Surface Vehicles (USVs) would be able to efficiently collect plastics without the need for human interaction.

System Overview

Our research aims to tackle the increasing problem of pollution in our oceans, specifically microplastics, by utilizing a system of UAVs and USVs. The UAV will fly above the surface of the water scanning for microplastics and the USVs will collect it. Our system will cover an area of 41.6 km down the coast and 10 km out to sea. Our collection system's volume is 0.18 m^2 or 180 liters which would allow collection of approximately 36 million microplastics at 100% efficiency. Accounting for the degradation of systems efficiency, we can average approximately 85% efficiency or 30.6 million microplastics.

Case Study – Monterey Bay

Our system of UAVs and USVs is versatile and has the theoretical capability to be implemented in a multitude of places. We decided to implement it onto a coastline, as we wanted to prevent plastics from going further into the ocean. We selected the Monterey Bay coast in California for our case study for multiple reasons. Compared to several other jagged coasts we considered, the Monterey Bay offered a simple curved shape to implement our system. In addition, it is located in a climate that offers the lowest threat of unpredictable weather. The optimal months of operation would be between May and September, only during daylight hours. Our system could theoretically be scaled and implemented into many different places with different climates and terrain.

Fig. 1 Overview of Monterey Bay, California.

Approach

System Design

To address the problem of plastic pollution in aquatic ecosystems, this research proposes a system to detect and collect microplastics near coastlines using unmanned aerial and surface vehicles. To start, a fully charged aerial drone is deployed from the southern start of the bay at Old Fisherman's Wharf where it will begin to follow a flight path to survey a designated area. In this case, it would cover the entirety of Monterey Bay's coastline from the southern launching pad to the northern edge near Tannery Gulch. The UAV is joined with two sensor systems; one to recognize plastics on the water surface and one for underwater detection. After the area has been surveyed, the gathered data is sent to a team on a boat that uses the data to deploy the collection system, which is a USV equipped with a plankton net. From there, microplastics can be collected and removed.

The main flow between the system's components is illustrated in Figures 2 and 3. The detection portion of the system is made up of the survey UAV and its sensors. The role of the survey UAV is to essentially provide an aerial view of the water's surface. The optical camera, along with an object detection algorithm, is used to recognize larger macroplastics on the surface. Then, the Photoacoustic Airborne Sonar System (PASS) is used to detect microplastics that are underwater, where the optical camera cannot see through. After, the information gathered is communicated with a crewed boat, and from there the system operators can deploy the collection system. The collection system is a USV, with the role to collect the detected plastics. As shown in Figure 3, once the collection task has been completed, the USV can return to the boat for recharging and to let the crew remove the collected plastics from its net. Apart from the collection system, the UAV also has a charging station, which is a tower built on land along its path. The charging station allows the drone to have adequate power for continued flight and survey.

To ensure the system's success, it must meet several criteria. First, it must have the ability to detect and collect microplastics. Second, the system must also have effective communication between its components. It should also be environmentally safe, meaning it should not harm aquatic life and is capable of differentiating plastic from organisms. Additionally, the UAV must be able to reach charging ports safely and consistently. Otherwise, there is the risk of damaging the drones, which would be costly and time-consuming to repair or replace. The result of the design is a sustainable system that is able to combat the growing problem of plastic pollution in Earth's water.

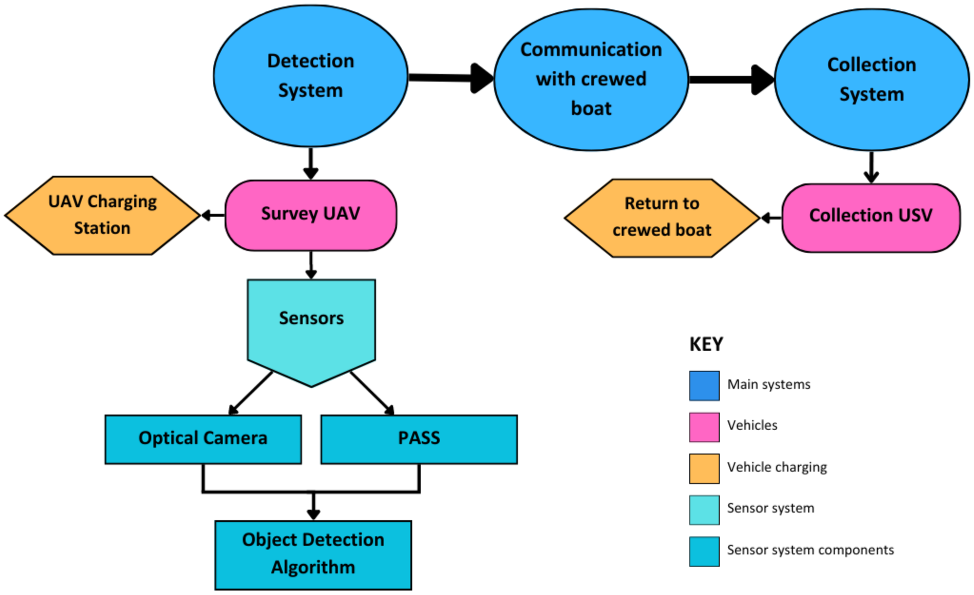

Fig. 2 Flowchart of system design.

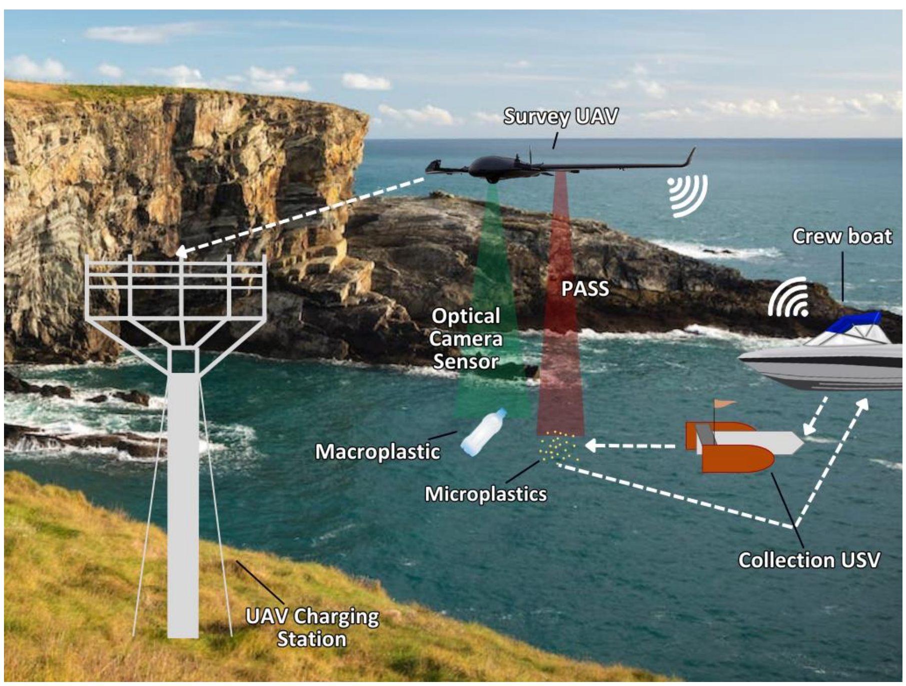

Fig. 3 Schematic overview of detection and collection system for plastics along coastline.

Surveying Drone

The first step in the collection process is to map out where microplastics are located in the chosen body of water. In order to do this, a UAV equipped with sensors will fly above the surface of the water following a predetermined path, using sensors and cameras to collect data about the location of microplastics in the water. The drone must be able to withstand the windy conditions above the water, follow the predetermined flight path autonomously, and have enough flight time to map the chosen body of water while carrying a camera and sensor payload.

A fixed-wing drone would be best suited for this purpose compared to a multi-rotor drone. This is because the drone will primarily move horizontally as opposed to vertically, and it doesn't need to hover during the mapping process. Fixed-wing drones are also better suited to handle the windy conditions at sea [5].

We selected DeltaQuad Pro #MAP as a candidate UAV meeting these requirements. This drone has a range of 100 kilometers while carrying a 1-2 kilogram payload, and can operate autonomously, reducing the need for human operators. It can also handle adverse weather, particularly rain. It is a fixed-wing drone, but unlike most fixed wing drones it also has vertical takeoff and landing (VTOL) capability. This means it can take off from places without runways, making it possible to use in a wider range of locations [6].

In the case study, 400 square kilometers of the Monterey Bay need to be mapped. It is best to complete the mapping process in a day, so the data is as recent as possible. The drone can only operate during the day because it uses optical cameras, leaving approximately 10 hours of flight time for the drone to operate. Since this drone travels 100 kilometers per flight and has a flight time of 110 minutes, it would take less than 8 hours to map out the entire area, charging time included. This means for our case study, only one drone is needed to map out the entire area in a day. For other systems, this amount can easily be scaled based on the desired area to cover. Multiple drones can also be used for redundancy, to ensure correct data in case anything goes wrong with one of the drones. It is important to consider cost and available resources when deciding how many drones to use for the mapping stage, and this number can vary in different situations.

Sensors

Sensors are a crucial component of the system design. They allow the survey vehicle to recognize and detect plastics in water. The team proposes that the system have two levels of sensors, optical and sonar. With different sensors, the collection process would work more efficiently and have greater impact. Both sensors on the survey drone would provide reliable data to the collection system, so as to conserve energy and time.

Optical Camera

The first level of sensing is an optical camera. The role of the optical camera is to survey the surface of the ocean's water for macroplastics. Based on its data using image recognition, if plastic is detected on the surface, it can be assumed that microplastics and other macroplastics may be present nearby as well. The DeltaQuad Pro #MAP provides the option to include mapping payloads. From the payload options, the Sony A7R mark IV proves to be a top choice. The 61-megapixel camera has the highest image resolution of 9504 x 6336 and can be combined with a full frame sensor [6]. Additionally, it can be efficient in coastal environments as it has image stabilization and is environmentally sealed.

Photoacoustic Airborne Sonar System

The survey vehicle also includes the second level of sensing which is based on Stanford's "Photoacoustic Airborne Sonar System" (PASS) as illustrated in Figure 5. Although still in experimental phases, the sonar system seems to be a promising way to detect objects underwater from the air. Currently, the main objective of PASS is for underwater imaging, however, it can be easily applied to detection. In order to achieve this, PASS utilizes laser generated sound and sensitive sound sensors [8]. To illustrate, the drone would have a laser that fires light to a mirror that deflects it down to the water's surface. When the water absorbs this light, sound waves are made from reflecting off the underwater object. Some of the sound waves pass through the water's surface, and when those waves do, a sonar sensor receives the energy to convert into signals that detect the targets. To receive the acoustic signals, the survey vehicle would have an array of capacitive micromachined ultrasonic transducer (CMUT) sensors attached onto the bottom of its wings [9].

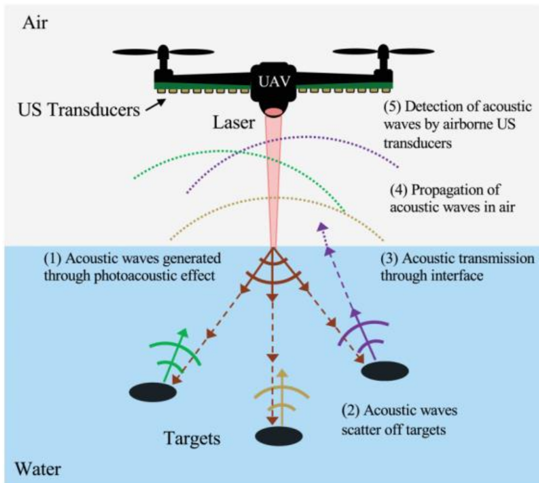

Fig. 4 Schematic diagram of PASS by [Aidan Fitzpatrick]() is licensed under [CC BY-NC-ND 4.0.]()

Object Detection

As previously mentioned, the system uses image recognition to detect plastics. Image recognition would be part of an object detection algorithm. There are two approaches to object detection, traditional image processing and deep learning. This paper recommends the use of deep learning in image recognition. Deep learning is proven to have higher accuracy and efficiency as it can provide real-time data. For example, the You Only Look Once (YOLO) model is one of the latest and fastest algorithms for object detection [10]. As a matter of fact, a project called *DeepPlastic* has used YOLO to identify marine plastics [11]. Receiving instant results is important for the system's purposes as plastics are moving with the ocean waves. Despite the training time and resources it may require, deep learning is an effective approach to detecting plastics [12].

Algorithm & Communications

In order to navigate both the Surveying Drone and the Collection System, using pre-built mapping software would work best with our given drone. The flight path of our drone is determined by the given parameters of the drone and what area we want it to cover. For our case study, Monterey is 40.2 km across and we want to travel halfway to the territorial sea which is 10 km. The drone can travel 100 km at maximum if at cruise speed and can go 50km away from the boat for image feed [6]. We can use trigonometry to measure the Field of View (FOV) of our given camera using the equation: Sensor Length divided by Focal Length multiplied by distance to subject equals Linear FOV in meters where sensor length is in mm, the focal length is in mm, and the distance to the subject in meters. Given our case camera being a Sony A7R mark IV, with a focal length of 35mm and sensor dimensions of 35.70mm x 23.80mm, with a height of 100 m we can calculate the FOV being 102 m by 68 m or 6.936 km^2. This is important because it lets us know how much area can be covered by the drone and lets us better calculate the flight path of the drone. At a height of 100 m, the Ground Sampling Distance (GSD) is about 1 cm/pixel so the camera is still able to accurately track macroplastics from that height. Using surveying mapping software like DroneDeploy would allow a flight path to be accurately designed [7]. Using such a design yields a flight pattern as shown in Figure 5 in a small part of Monterey Bay which uses zigzags to survey the entire area.

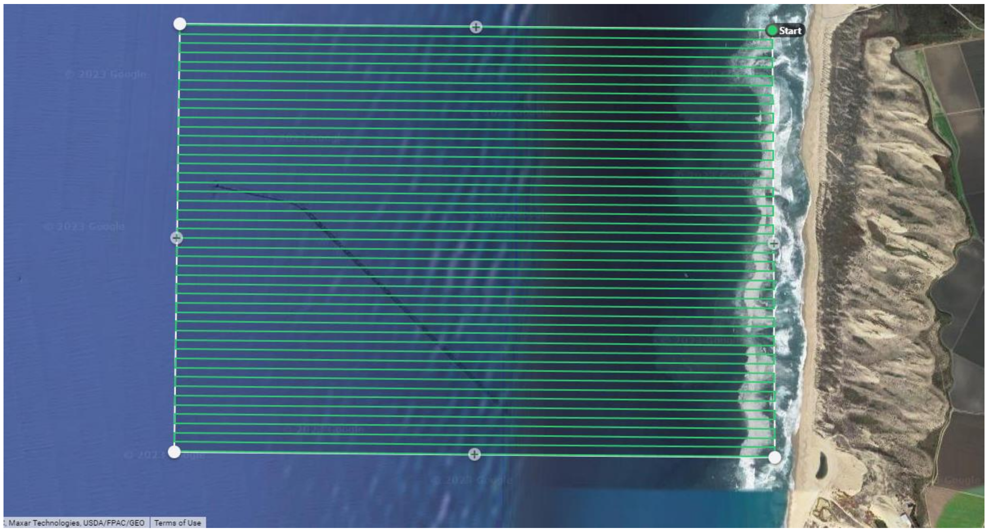

Fig. 5 DroneDeploy's predicted surveying path for a small part of Monterey.

Because of the width of the FOV, the length between each zigzag will be 102m, and will plan to go 10km out to sea as shown in Figure 6 which covers half of Monterey Bay.

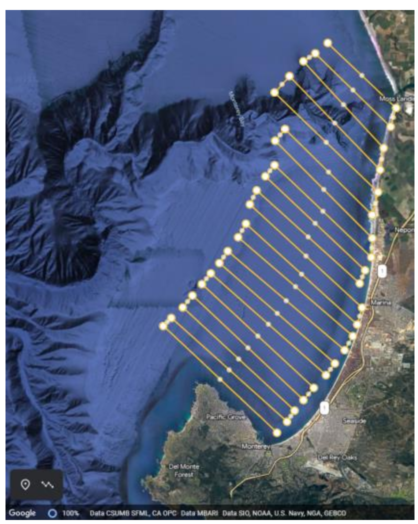
Fig. 6 Example pathing for a surveying drone covering half of Monterey Bay.

Considering the desired area to cover is 41.6 km and the battery of the drone holds 100km, the drone can travel 9 times across before needing to recharge with 9 km between each station. To travel the 41.6 km, we will need 4 charging stations ideally considering ideal conditions. The flight time at that speed is then 1 hour and 50 minutes under ideal conditions, and approximately 1 hour is required for recharging the system's vehicles. Therefore, the entire process should be completed in a day. The charging of the UAV will be done autonomously, while the charging of the USV will be done using hands on human operation. This will be further discussed in the "Charging Station" section of this paper.

To communicate with the boat, the drone will be sending a live video feed to the ground controller plus using a Real-Time Kinematics (RTK) kit to send location details. The range of the live video feed is 50 km so as long as the boat is within 10 to 50 km away from the coastline the drone should be in range and the video can be processed via the live video feed. RTK is used while the drone is surveying and allows the boat to collect geographic data from the drone to an emitter on the ground. This can also integrate with the PASS where once it detects a plastic, it can send a radio signal to the boat and the RTK emitter will allow people to track where plastics have been detected. Then the collection system is used to collect any microplastics while the drone continues surveying.

Collection System

The use of common plankton nets would allow for the collection of most microplastics while preventing most drag from the water. Standard plankton nets come in mesh sizes of 300-390 microns while most microplastics are sized from 1-1000 microns meaning plankton nets will be proficient in capturing most microplastics as well as larger macroplastics [13]. Other ways of collecting microplastics include using magnets or membrane technology. For the purposes of the case study, magnets would not be strong enough to catch most plastics in the ocean, and membrane technology, although efficient, would not be energy or cost-effective. Plankton nets provide an efficient and reliable means to collect most microplastics.

To collect plastics based on the survey drone, we integrate a plankton net with a Portable Catamaran Drone (PCD), a USV that has a frame, floatation device, and a plankton net with a cod-end to collect samples and can travel around 24 km in calm waters [13]. Standard plankton nets are about 60cm x 25cm and have a length of 350 cm to prevent significant drag. This solution allows for the collection of all surface microplastics and those located around 50 cm under the water. The drawbacks of using this type of drone would be that it would be difficult to collect any plastics below 50cm under the water's surface. Another drawback would be that the PCD would only reliably collect plastics in calm sea states with a wave height of less than 2 meters.

This would integrate into the system while the drone is surveying the area, it can use the RTK to figure out locations of macroplastics and microplastics sensed by the camera and sonar. Using live video feed and the active sonar system, the boat moves along the coast with the drone and will use this data and analyze it in real-time to make it so that whenever plastics are sensed, they can send the PCD right away. This process allows for minimal movement of the plastics and quick collection to make the system overall more efficient. After this, as long as the boat is within 10 km of the area, we can send out the PCD to collect the plastics and return back. This system is easily scalable with multiple PCDs being able to go out at once and be collected after.

Battery & Charging

Battery

Supplying power is a crucial step in this system. The DeltaQuad Pro #MAP is powered by a Lithium-polymer (Li-Po) battery [6] which is produced by MaxAmps [14]. The battery contains 23,000 mAh and 14.8 V and will allow over a hundred minutes of runtime and use.

The PCD runs off of a Lithium-ion (Li-ion) battery. The included battery is the Makita 1850B and it contains 5000 mAh and 18V [13]. This supplies enough power to the PCD to run for one hour.

If upgrades were to be done to the battery, only the DeltaQuad Pro #MAP would have a reasonable upgrade. Tattu manufactured a Li-Po battery for the DeltaQuad Pro #MAP. Costing $532.99, it contains 30,000 mAh and 22 V. This battery is efficient and will allow the drone to run for more than 140 minutes [15].

Because of the lack of technology, there are not many efficient upgrades for the PCD which would be reasonable with pricing. It is difficult to find batteries which match the requirements of the PCD; Li-ion battery which connects with sixteen contact terminals. The Makita 1860B is the newest manufactured battery by Makita. It contains 6000 mAh and 18 V. However, for $220 the drone gains just 10 minutes extra runtime than the Makita 1850B [16].

Charging Stations

Recharging stations are necessary for the system to operate. Quick and easy to maneuver charging stations are needed in order to maintain the system's speed. Using charging stations placed in specific spots along the coast, the drone will have the ability to recharge when necessary in the quickest way possible. Each station will consist of a tower that uses the principle of electromagnetic induction. The drone will fly into the bowl-like charging station placed atop the tower and hover there and power the drone wirelessly until the drone has full charge, taking less than ten minutes [17]. The PCD will operate with a different charging system. It will receive its charge from the collection boat and will take longer to charge than the UAV. The charging time for the battery model, Makita 1850B is about 45 minutes. Depending on its distance from the boat itself, the PCD will return when its battery percentage is low enough, docking with the boat and both charging its battery and dumping the plastics it has collected. The boat will house all collected plastics and a human crew will dispose of it properly.

Given the flight path and flight time of the drone in ideal conditions, we can calculate the placement of the charging stations as well. To travel 41.6 km, the approximate distance of the desired area, we will need 4 charging stations spaced 9 km apart along the coastline as shown in Figure 7. A downside of this design is that this considers ideal conditions and ideal charging which wouldn’t always happen in the Monterey Bay. However, for the purposes of this system and given current technology, such a design would function for our drone.

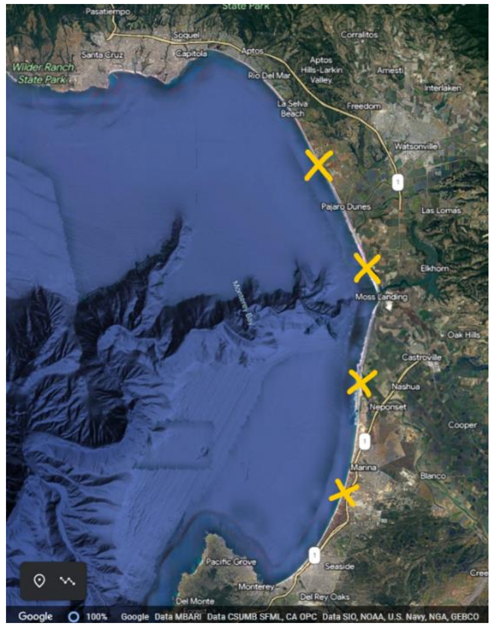

Fig. 7 Placement of UAV charging stations along Monterey Bay coast
(X marks approximate locations).

Conclusions

In summary, we designed a system to remove macro and microplastics from Monterey Bay and selected the type of unmanned vehicles suitable to remove them. The proposed approach uses UAVs and USVs as a surveillance and collection system to pick up microplastics in the Bay. The sensors on the UAV drone are to be used to track and locate groups of macroplastics and microplastics in the Bay. The algorithm and communication system allows for accurate mapping and accurately processed data from a boat helping the system. The collection system of USVs with plankton nets then collects the detected plastics. The net needs to be sized for the drainage of water for the maximum performance of the USV. The location of the microplastics in the water, as well as the water conditions, impact the performance of the collection system. If the items are located too far off of the shore or the depth is out of reach, the collection won't be possible. The battery and charging stations of the UAV are critical to how long the UAV can stay in service. Suitably designed locations along the coast enable the UAV to perform efficiently and return to the base for future expeditions.

Our system design is limited largely by technology and weather conditions. For instance, the system cannot be fully autonomous because of the need for someone to monitor the surveying drone and release collection drones safely. The PCD is only to run in calm sea states and is not designed to handle harsh sea conditions. It is also not able to collect plastics more than 50 cm under water. Additionally, the current sonar technology has difficulty differentiating between different objects underwater. Finally, image recognition is not the most accurate in certain conditions.

Unfortunately, because of the availability of technology, there are no solutions to these problems just yet. However, there is a way to limit the inaccuracy of sonars, but it will decrease the speed of the whole process. Narrowing the path of the signal of the sonar ensures more accurate results. For the collection system, creating new technology for more underwater drones or larger plankton nets would solve the issue of not being able to collect plastics under 50cm, but may also be less efficient and more prone to weather conditions. Some additional research should be done on how weather conditions would affect sonar and image recognition as well as research on the PASS to see its reliability for microplastics. For the time being, our proposed solution provides a semi-autonomous way to speed up and reliably collect macro and microplastics in most weather conditions.

This system is easily adaptable and scalable, so it can be used to collect microplastics in a variety of locations. Some potential alternative locations in the United States of interest are San Francisco Bay, Oahu, Kamilo Beach, Florida Keys, and the Great Lakes. The Great Lakes may require a change in the sensors used to be able to detect microplastics more efficiently in freshwater. This system can also be used to collect larger plastics. This would eliminate the need for the Photoacoustic Airborne Sonar System since the optical camera alone can identify these plastics. This would also require changes in the collection system, as the fine mesh plankton net is no longer necessary. The mapping portion of this system can be used to map the ocean in a variety of ways. The Photoacoustic Airborne Sonar System can be adjusted to locate specific types of objects, or even to produce a diagram of the ocean floor. In this case, the collection system component could be eliminated.

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