Sea Debris: A Review of Marine Litter Detection Techniques

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***Abstract* - Debris produced by humans is usually released into the natural underwater environments such as rivers and oceans. Spotting marine debris in rivers and oceans is crucial to recognize and diminish its impact into the ecosystem. Present monitoring methods of manually determining the amount of debris present in the oceans is time consuming, labor intensive and limited in coverage. The aim of this study is to supervise and conserve aquatic and coastal ecosystems from pollution. This paper identifies various marine debris detection techniques such as image processing, deep learning, trawling which can prove as effective counter measuring techniques. Analysis of debris using publicly available datasets being made by a few papers is also presented in this study. Various methods being discussed can be used for later analysis for the development and effective management of debris, thus conserving our ecosystem.**

***Index Terms* - Marine Debris, Debris detection, Deep Learning, Image Processing, Trawling**

1.INTRODUCTION

Every year, tons of plastic and other garbage are either pushed into the aquatic environments or left on the beaches or disposed of or abandoned. Not only does the garbage look unpleasant but also poses a threat to the economy and the environment. Accumulation of trash in aquatic environment leads to ecosystem destruction of marine life and poses a long-term threat to the environment. Marine debris can last for a long period of time. Debris is pieces of rubbish or unwanted material that are spread around. Marine debris is defined as solid man-made material that can be directly (from ship or ocean platform), indirectly (from storm drains, etc.), purposefully dumped or accidentally abandoned into our aquatic environment or the Great Lakes.

The history of marine debris draws back from entanglement reports and ingestion of plastics in the 1960s. In the early 1970s, research interests were found from reviews revealing plastics present on the seafloor and having a strong effect on marine animals. Looking at the growing concern of impacts from marine litter by the early 1980s resulted in a series of meetings on marine debris. By the end of 1980, issues related to marine litter were well understood and observation was shifted to develop effective solutions to address the marine litter problem. Over the last few decades, there has been a dramatic growth in the production of plastic with around 288 million tons of production in 2012 and keeping up at about 4% per year [3].

Increasing amount of garbage in the world's ocean is becoming an environmental concern of our time, harming the ecosystem, killing the animals, and putting human health at high risk. Wastes end up in the oceans via rivers and sewage pipes through winds. Wastes from boats and ships also accumulated in the ocean making garbage patches. Currents and winds sometimes carry marine debris faraway from its source in the ocean. Garbage patches are the areas present in the sea where marine debris gets accumulated due to currents and winds. These areas cannot be seen by naked eyes and are mostly made up of tiny microplastics.

Globally, 73% of beach litter is plastic, residue from cigarettes, bottles, wrappers from food, shopping bags and thermocol vessels [2]. Over 200 species are affected by entanglement. More than ⅓ of all seabird species eat debris. All sea turtle species eat debris [1].

Fig. 1.: List of top ten Debris items [1]

The above list of items is taken from Maine Debris Monitoring and Assessment Project (2012-2018) from around 4400 surveys from 9 countries having 330+ monitoring sites. Plastic is the most frequent category of marine debris present in the oceans. As plastics are non-biodegradable in nature, they do not biodegrade in the oceans and get fractured into tiny pieces called microplastics due to exposure from sun and weathering. Approximately nine million tons of plastic waste end up in our oceans each year and lasts for hundreds of years there.

2. LITERATURE SURVEY

It is necessary to identify the methods used to evaluate debris and how the results are presented and interpreted. Determining what happens to debris present at the deep sea with time is very little known. Around a dozen researchers have only stared at debris beneath 500m.

Severe technical obstacles and costs of conducting investigations in the deep sea are the problems faced during detection of marine debris. Technology driven methods can lead to development of effective solutions.

Table 1. Marine Litter Monitoring Techniques on Sea Floor

Monitoring techniques	Observations	Limitations
Trawling and Counting	Most accurate method and is in use since 2011. Sea areas should have smooth and flat bottoms. Highly expensive equipments are required.	It is labor consuming and expensive as well. Degree of detection may be affected and will depend on the diver's experience.
Monitoring by Scuba Divers	Monitoring done near shores in shallow water with depths less than 20m. Necessary resources to divers are provided. This method is simple and cost effective as it does not require a high level of expertise.	Degree of detection may be affected and will depend on the diver's experience.
Monitoring by Video Cameras	Areas having water depth greater than 20m are usually inspected by cameras. Special equipments such as Remote Operated Vehicles (ROVs) and submersibles are used. This method demands for less human resources and is cost effective.	Technical failures and bad weather conditions can be a concern while using this method.

2.1 Available Datasets for Analysis

Marine Debris Tracker

Debris tracker [5] is an open data citizen science movement. According to them, they are committed to sharing their data because they believe that this problem will be solved more quickly when we all work together. When we use the Marine Debris Tracker app, the geospatial litter data we collect is uploaded to Marine Debris Tracker's publicly accessible database. Scientists, policymakers, educators, or anyone around the world can download and analyze data to inform their solutions. There is power in numbers which is why they rely on the community just like us to collect the data. The app is free and easy to use. So anyone can become a citizen scientist.

Deep Sea Debris Database

The Global Oceanographic Data Center (GODAC) of the Japan Agency for Marine Earth Science and Technology (JAMSTEC) has launched this database in March 2017 for public use. This database provides type-specific marine debris data collected from deep-sea in the form of videos and photos. The videos and photos were taken during their surveys dating back from 1983 with the help of ROVs and submersibles and were assessed and documented in the database. Only a few cases have been surveyed over the deepest parts of the oceans and this database consists of marine litters present at depths greater than 6000m as well.

Self-Generated Datasets

1. Dataset used by [6] in their study was collected by bridge mounted video cameras at five different waterways in Jakarta, Indonesia. The dataset built by them consisted of two datasets, namely River Image dataset and Floating plastic dataset.
2. Dataset used by [7] in their study was collected by capturing Forward Looking Sonar (FLS) images with ARIS Explorer 3000. Around 2000 images were captured inside a water tank with different

types of debris objects. Final dataset of 22446 96X96 images was obtained for model training.

2.2 Methods used for detecting marine debris

As per the experiments performed by [9], quantification of floating macro-debris on river surfaces was done using an image processing approach. The algorithm developed consisted of implementation of three techniques: (1) A difference image was generated based on the color contrast between litter and the adjoining water using the CIELuv color space. (2) Using the difference image, pixels of litter were detected by binarizing using the constant threshold value. (3) Debris area flux (debris moved per unit time) was computed using the template matching technique. Extraction of debris pixels for large items was difficult using this algorithm because pixels present all over the periphery of litter were spotted using edge detection algorithm, but the pixels present around the center were not detected using this algorithm. To compute the performance of the given algorithm, experiments on both laboratory and river were conducted. Future scope suggested by authors is to judge large pieces of floating debris by using this algorithm to videos recorded under numerous flow conditions.

A deep learning based automatic identification of floating marine plastic is stated in the paper by [4]. The proposed model was trained on three different types of marine plastic wastes consisting of bottles, buckets, and straws. A Visual Geometry Group-16 (VGG16) Convolutional Neural Network (CNN) architecture model trained prior on the ImageNet database is proposed in this study. Fully connected layer from the model is removed and bottleneck features learnt from pre-training were then used to train the fully connected layer. As described in the paper, few datasets have relatively low images. They initially had around 250 images of each class. So, they have implemented by augmenting the images into 4000 images of each class. Training accuracy of ≈100%, testing accuracy of ≈99% and validation accuracy of ≈86% was achieved for recognizing the preceding floating plastic marine litter. Accuracy with respect to use of different regularizes is also presented in this study. Future scope suggested by authors is to use more advanced deep learning models and distinguishing between more classes of marine debris.

Recent work demonstrated by Colin van Lieshout [6] proposed a research where automated techniques for tracking plastic pollution in rivers and sea were used. The dataset used in this study is described in 2.c.i. Three experiments performed were presented in this study: (1) Determination of precision of the used method and its dependence on training data and training algorithm settings. (2) Generalizing the trained method to new locations. (3) Comparison of automated model with human performance. The method described consists of two phases: a segmentation phase and a detection phase. Both of these phases were executed using TensorFlow Object Detection API. Faster R-CNN algorithm is used for implementing the segmentation phase and Inception v2 network pre-trained on COCO dataset is used for detection phase. Segmentation phase is used for selecting promising regions from the given image likely to contain plastic objects and detection phase is used for selecting the image regions that contain plastic waste. Precision of ≈59.4% was achieved without optimizing the algorithms settings. By optimizing the algorithm settings, precision was improved up to 68.7%. Future improvements as suggested by authors can be done on dataset, sensors, segmentation, and detection. Data augmentation and image distortion can also be applied to increase the performance of the system.

Matias Valdenegro-Toro [7] in 2016, designed a four-layer CNN architecture for the use of Autonomous Underwater Vehicle to detect underwater marine debris from FLS imagery. The approach described for detection of marine litter using FLS images consisted of two main components: Preprocessing of training data and the use of Convolution Neural Networks. The model was trained for spotting objects in the sliding window fashion. Dataset used for the training method is described in 2.c. ii. 80.8% correct debris detections were made when trained using a binary detector and 70.8% correct debris detections were made when trained using a multiclass detector. Results presented shows that the classifier was having an average accuracy of 97.1% with low confusion between different categories. Future improvements as suggested by authors can be in terms of data collection, consideration of deformed state of objects, manipulation and interference of a machine that can look over, recognize, and retrieve underwater debris.

A thesis on the use of Deep Neural Networks (DNNs) to identify and recognize marine litter in the deep seabed using the FLS images as stated in [18]. This thesis performs evaluation for solving underwater trash detection using DNN as well as for problems related to it such as classification and matching of images.

In the paper by [10], authors have discussed about Robotic detection of marine litter and evaluated 4 deep learning architectures for the detection of trash present in aquatic environments. Dataset used for training the model consists of three classes, namely Plastic, ROV (all man-made objects) and Bio (all-natural biological materials) taken from the JAMSTEC library of deep-sea images (J-EDI) dataset of marine debris described in 2.b. Network architectures being described are YOLOv2, Faster RCNN, Tiny-YOLO and Single Shot MultiBox Detector (SSD). Different performance metrics are used for model evaluation. Each algorithm has its own advantages as well as downsides with different runtime speeds and accuracy. Future improvements as suggested by authors can be done on data from real world environment, navigation can be developed, and on handling strategies to find trash in water in large quantities.

[11] proposed a research of enhancing underwater imagery using Generative Adversarial Networks (GAN). The approach described in this paper is the use of the CycleGAN approach. It learns to render an image from any random field X to another random field Y without image pairs, generating a paired dataset. X is defined as the set of unaltered submerged images and Y is defined as the set of altered submerged images. CycleGAN performs style transfer when given a field of submerged images with and without alteration. When an undistorted image is fed to the CycleGAN, distortion of the image takes place which looks as if the image was taken from the distorted image domain field. These pairs of images are then used by the algorithm for the purpose of image reconstruction. Future improvements as suggested by authors can be made on generating a huge and more disparate dataset from submerged objects. Data created by CycleGAN can be augmented with noise with effects of lighting to improve the variation of the dataset.

As described by the study made by [12], areas having higher chances of debris accumulation are identified using a multistage modeling and remote sensing approach. Author described that a sampling master plan must be made to look for small items rather than searching the entire ocean. Systematic and Stratified sampling strategies are being defined. Once the level is determined, measurements either direct or indirect must be made to locate the presence of debris. Presence of debris materials using contact or remote sensing is made using direct measurements. Mapping the attributes of the environment to the areas where debris items can be found is made using the indirect measurements. Remote sensing resolution either spatial, spectral, or temporal is used during direct measurements. As few debris items present in the oceans usually are in motion, information about the location of the items is present for a short span of time. Thus, the search strategy must be made with respect to small time steps. Sensors and platforms used for analysis considerations must be made by keeping the surrounding parameters in mind. This paper presents a study of overview of various technologies, processes for the detection of marine debris.

An observation of debris present at the seafloor around Monterey Canyon is examined in the paper stated by [13]. A review of around 1149 video recordings of marine debris was made from ROVs operated for 22 years with depths ranging from 25m to 3971m. Debris items which were found dominant were plastic and metal having their existence in the range of 2000m to 4000m. A similar study has been made by [14] where observation records of a 30-year database as described in 2.b. is examined. According to this study, plastics present deep in the oceans are usually single use products and have reached greater depths with the deepest being recorded at 10898m. These both studies demonstrate that debris items have reached deep into the oceans and regulations on the use of such products must be made to prevent further threatening to our ecosystem, thus will help us to save our biodiversity.

Sensors and computers can outperform human eyes and brain in some tasks such as working outside the gamut of human sight, processing information unavailable to the human vision system, providing records that can be used at later stages for analysis, producing more objective based, focused results. This paper study as described by [15] aims at spotting vast marine debris in oceans with the help of airborne sensors. Use of different active and passive sensors are being presented such as digital camera, infrared camera, lidar (light detection and ranging), radar (radio detection and ranging), etc. Research highlights made on the basis of this study are: (1) Use of filtered multi-spectral camera in all types of aircrafts will be a cheap, effective platform for digital images. (2) Sensing devices like lidar can enlarge the performance of the system but will also increase the cost and the complexity of the system. (3) None of the sensors is capable of detecting all debris. So, sensing devices suitable to the inspection conditions can provide the most desirable solution to the problem of debris detection.

In the paper by [16], authors have discussed the descattering and color correction method for amplifying high turbid underwater images which helps in preserving the color of the image and remove scattering. An image quality assessment index combining the benefits of Structural Similarity (SSIM) and color distance index is proposed for comparing the performance of different used algorithms. An underwater imaging model is being presented which is then enhanced using the depth map refinement using the guidance image. After the use of depth map refinement, distortion of color takes place which is then addressed using the color correction method. Comparative analysis of different enhancement algorithms is being presented in this study. 7330 images from categories of four classes were taken from the database of JAMSTEC for this experiment. Future scope suggested by authors can be made by designing new deep learning-based algorithms for scatter removal.

Experiments performed as stated in [17] studied the methods for evaluating the amount of litter present on the bottom of the oceans. Investigation of marine debris was done using the four methods, namely bottom trawling, pole trawling, video photography and submersibles. Runs of around 10 to 60 minutes were conducted and debris of 7 types were found. It was found during the research that plastic objects accounted for greater than 90% at some sampling stations and large amounts of plastic objects were found in deep areas than on the areas submerged under shallow water. Some areas had concentrations of more than 200 debris pieces per hectare. Results showed that the most suitable method for larger areas was pole trawling while for smaller areas worn away by the action of water, the most suitable method was submersibles.

In January 2016, a group of technologists, experts in the field of marine debris were brought together by a workshop sponsored by NASA as stated by [19], the aim of which was to review the present methods, state-of-the-art technologies capable of remotely sensing the marine debris present in the ocean. An overview of instrument considerations is also presented. Lack of information to some of the broad science questions required the attention to be shifted towards the further development and demonstration for solving the problem of marine debris. This paper summarizes observations and states the objectives of this workshop.

A surface trawling method integrated with three other ocean circulation models is being presented in the study demonstrated by [19]. 15 to 51 trillion microplastic particles accumulated in the year 2014 which is only ≈1% of the global plastic waste estimated to set foot into the ocean in the year 2010. Implementation methods being discussed in the paper includes the Data standardization using statistical modeling, Plankton surface-trawl dataset coupled with the Ocean Circulation models consisting of Maximenko model [20], Lebreton model [21] and van Sebille model [22]. Total microplastic concentration observed is the highest noted from van Sebille model, followed by Lebreton model and Maximenko model. This paper analyses a framework to geographically introduce observations made to the problem of floating plastic debris.

The different techniques used for Sea Debris Detection are shown in figure 2.

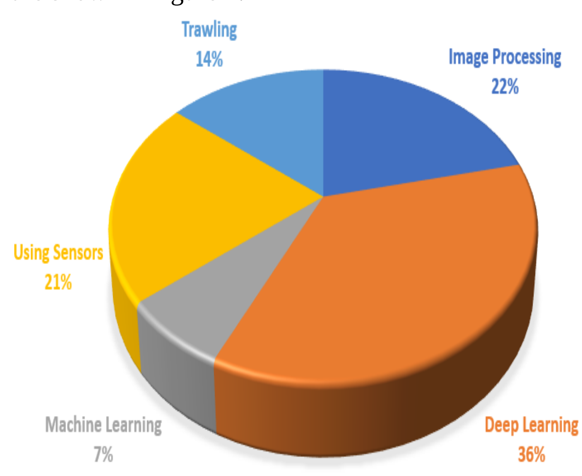

Fig. 2.: Various Debris Detection Techniques found in our survey

Table 2. Comparison of Various Debris Detection Algorithms

Paper	Algorithm Used	Observations	Future Scope
Kataoka et al., 2020	Image Processing Approach based on Difference Image Generation using CIELuv color space, detection of litter pixels, and computing Debris area flux.	Extraction of debris pixels for large items was difficult using this algorithm.	Judging large pieces of floating debris to videos recorded under numerous flow conditions.
Kylili et al., 2019	Deep learning based VGG16 architecture	Identification of floating marine plastic consisting of bottles, buckets and straws. Training accuracy of ≈100%, validation accuracy of ≈86% was achieved.	Using more advanced deep learning models and distinguishing between more classes of marine debris.
Fulton et al., 2019	4 deep learning architectures - YOLOv2, Faster RCNN, Tiny-YOLO and Single Shot MultiBox Detector (SSD)	Dataset taken from JAMSTEC Marine Debris dataset, consists of three classes namely, plastic, ROV (all man-made objects) and Bio (all-natural biological materials).	Collecting data from real world environment, navigation can be developed, and on handling strategies to find trash in water in large quantities.
Fabbri et al., 2018	Generative Adversarial Networks (GAN) - CycleGAN approach	CycleGAN performs style transfer when given submerged images with and without alteration. When undistorted image is fed to the CycleGAN, distortion of the image takes place.	Data created by CycleGAN can be augmented with noise with effects of lighting to improve the variation of the dataset.
Valdenegro-Toro, 2016	Designed a four-layer CNN architecture	Autonomous Underwater Vehicle to detect underwater marine debris from FLS imagery. Approach consisted of pre-processing of training data and the use of CNN.	Data collection, consideration of deformed state of objects, manipulation and interference of a machine that can look over, recognize and retrieve underwater debris.

3. DISCUSSION

Marine debris is everyone's problem [1]. It affects everyone from our economy to our environment, from small plants and fishes to giant whales and comes in many forms from residue of cigarettes to bottle caps to car parts. It can threaten marine life as well as our oceans and coasts. Even it affects us as well whether we are enjoying holidays over the beach or boating.

Fig. 3.: Debris items counted worldwide using Marine Debris Tracker Application [5]

This paper has taken a deep dive to understand underwater trash and floating marine debris detection techniques. Most recent papers in this domain were considered for the study. It is observed that discussions about marine litter have widened over the last few decades as the issue has been brought into the eyes of the public worldwide. These sea debris have a huge impact on environment and living beings. It is clear from the facts that the debris released from land must be captured before being released into the ocean as the impacts of marine debris have become an environmental as well economical concern of our time. It is observed that image processing and machine learning techniques were widely used for sea debris detection. Deep learning techniques are also being used by researchers because of its proven advantages in other application areas. Still there is a scope of building robust systems which are more reliable than from the current state-of-the-art methods. To improve the current state-of-the-art methods, focus should be more on collecting datasets free from noise with the use of advanced sensors and instruments and should be made available to the public so that more effective countermeasures can be made. Hence, a technically adequate world can help us to solve the problem of marine litter with the use of emerging technologies.

Persons who actively visit beaches may avoid going to certain beaches because of mess up by marine debris. At 31 beaches in Southern California, the National Oceanic and Atmospheric Administration (NOAA) estimated the amount of money that could be saved reducing marine debris. [1] Around 32 million $ could be saved if litter is reduced by 25% and around 67 million $ could be saved if litter is reduced by 50%. There are numerous impacts caused by marine litter either to the environment or to the economy. Some of them are given in Table 3 below.

Table 3. Impacts of marine debris [1]

Eatables	Animals sometimes by mistake eat plastics and other litter present in the sea.
Navigation Hazard	If marine debris is floating below the water's surface, it can be difficult to see in the ocean.
Damage caused to Habitat	A large proportion of marine debris can crush habitat which is sensitive in nature such as mangroves, seagrass beds.
Offshore species	The species are transported from one region to another by marine debris.
Cost of Economy	Cleaning of trash costs a lot of money for the communities.

Keeping an eye on the debris entering the rivers is crucial as debris when released is transported far away into the oceans due to winds and storms. National Geographic in partnership with Wildlife Institute of India, University of Dhaka and Wild Team is documenting how plastic waste travels from source to sea which will help in development of effective solutions to this problem [2]. During the analysis, one should answer three questions: What is it, how did it get there and together What can we do about it? It is the need of the hour that we should understand the concern of litter entering into our oceans, disturbing our biodiversity, and creating a long-lasting environmental impact.

4. CONCLUSION

This paper provides a depth literature review of many research papers based upon detection of marine debris using image processing, deep learning and the analysis being made in this field. From the study, it can be revealed that a system can be made for which dataset can be enhanced by scattering and color correction techniques and then using the segmentation and detection techniques to effectively create a system capable of underwater trash detection.

The future scope of the work is to explore emerging deep learning techniques than the current state-of-the-art methods, considering cost-effective instruments, using larger and diverse dataset with augmenting, image processing techniques can help build a robust marine litter detection system. In addition to these, building an automatic robot based marine litter detection and collection system will efficiently solve the problem with less human resources. This study can contribute to generation of more effective countermeasures.

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