

## ViT-Powered Underwater Trash Classification and Detection System

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### ABSTRACT

The increasing levels of marine pollution have become a critical environmental concern, particularly due to the accumulation of underwater waste such as plastics, metals, and other debris. Manual monitoring and cleaning of underwater trash are time-consuming, costly, and often inefficient. To address this issue, this project proposes a Vision Transformer (ViT)-powered underwater trash classification and detection system that leverages advanced deep learning techniques for accurate and automated waste identification. The system utilizes Vision Transformer architecture to analyze underwater images and classify different types of trash with high precision. Unlike traditional convolutional neural networks (CNNs), ViT models capture global contextual information, improving detection. The output of the system consists of labeled images with detected objects, which can be utilized for monitoring marine pollution, assisting in cleanup operations, and supporting environmental conservation efforts. Furthermore, the system can be integrated with real-time underwater robotic systems for continuous monitoring and automated decision-making. performance in complex underwater containing various categories of waste materials.. Overall, this project aims to enhance marine conservation efforts by providing a scalable accurate, and intelligent solution for underwater trash detection and classification, shapes. The model is trained on a labeled dataset of underwater images

contributing to cleaner oceans environments with varying lighting, turbidity, and object, accurate, and intelligent solution for underwater

trash detection and classification, contributing to cleaner oceans environments with varying lighting, turbidity, and object shapes. The model is trained on a labeled dataset of underwater images and sustainable ecosystems materials solution for underwater trash detection and classification, contributing to cleaner oceans and sustainable ecosystems materials.. Overall, this project aims to enhance marine conservation efforts by providing a scalable, accurate, and intelligent solution for underwater trash detection and classification, contributing to cleaner oceans and sustainable ecosystems

**Key Words:** Image Denoising, Underwater Trash Detection, Vision Transformer (ViT), Deep Learning, Underwater Image Enhancement, Object Classification, Object Detection, Marine Pollution, Environmental Monitoring, Self-Attention Mechanism.

## 1. INTRODUCTION

Marine pollution has emerged as one of the pressing environmental challenges in recent years, with vast amounts of waste accumulating in oceans and water bodies. Among various pollutants, underwater trash such as plastics, fishing nets, metal cans, and other debris poses a serious threat to marine ecosystems, aquatic life, and human health. These materials not only degrade water quality but also disrupt biodiversity and food chains. Traditional methods of monitoring and removing underwater waste rely heavily on manual efforts, which are often labor-intensive, time-consuming, and limited in scope. Moreover, underwater environments present unique challenges such as low visibility, varying light conditions, water turbidity, and complex backgrounds, making accurate detection of trash difficult using conventional techniques. With the rapid advancement of Artificial Intelligence (AI) and Computer Vision, automated solutions have gained significant attention for environmental monitoring. With advancements in technology, Artificial Intelligence (AI) and Computer Vision have emerged as powerful tools for environmental monitoring. These technologies enable automated analysis of images and videos, allowing for faster and more accurate detection of objects. Deep learning models, especially Convolutional Neural Networks (CNNs), have been widely used for image classification and object detection tasks. However, CNNs sometimes struggle to capture long-range dependencies and global contextual information in complex scenes. To overcome the limitations of traditional deep learning models, the Vision Transformer (ViT) has been introduced as an advanced approach for image analysis. Unlike CNNs, ViT uses a self-attention mechanism that allows the model to focus on important parts of the image and understand global relationships between different regions. This makes it highly effective in handling complex underwater environments where objects may vary in shape,

size, and visibility. The preprocessed images are fed into the Vision Transformer model, where each image is divided into smaller patches and converted into embeddings. Positional encoding is applied to retain spatial information, and the transformer encoder processes these embeddings using multi head self-attention to extract meaningful features. Based on these features, the system performs two primary tasks: classification and detection. In the classification stage, the model categorizes underwater trash into different classes such as plastic, metal, glass, and organic waste. In the detection stage, the system identifies the location of trash within images using bounding boxes and assigns confidence scores. To evaluate the performance of the proposed system, various metrics such as accuracy, precision, recall, F1-score, confusion matrix, and ROC curve are used. Experimental results demonstrate that the ViT-based model achieves higher accuracy and better generalization compared to traditional methods like Naïve Bayes and CNN-based models, while also maintaining competitive performance with real-time detection models such as YOLO. In conclusion, the introduction of a ViT based approach for underwater trash detection represents a significant step forward in the field of environmental monitoring. It provides a more accurate, efficient, and scalable solution compared to traditional methods, thereby contributing to the preservation and sustainability of marine ecosystems.

## 2. LITERATURE SURVEY

The study of underwater trash detection and classification has gained significant attention in recent years due to the growing concern over marine pollution. Various research works have focused on applying computer vision and deep learning techniques to automate the identification of underwater waste. Early approaches primarily relied on traditional image processing techniques such as edge detection, thresholding, and feature-based methods. These techniques were limited in performance due to variations in underwater

conditions like lighting, turbidity, and object distortion. As a result, their accuracy in detecting and classifying underwater objects was relatively low. With the advancement of deep learning, Convolutional Neural Networks (CNNs) became widely used for image classification and object detection tasks. Models such as ResNet, VGG, and YOLO have been applied to underwater datasets to detect marine debris. These methods showed improved accuracy compared to traditional techniques. However, CNN-based models often struggle to capture global contextual information and may not perform well in complex underwater scenes. Recent research has introduced Transformer-based architectures, particularly Vision Transformer (ViT), which have demonstrated superior performance in various studies. ViT uses self-attention mechanisms to capture long-range dependencies and global features within images. This makes it highly suitable for challenging environments like underwater scenarios, where object appearance can vary significantly. Several studies have also explored hybrid models combining CNNs and Transformers to enhance detection accuracy. Additionally, datasets such as TrashCan and other marine debris datasets have been used to train and evaluate these models. Researchers have also integrated these systems with Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) for real-time monitoring and data collection. Despite these advancements, challenges still exist, including limited availability of high-quality labeled underwater datasets, variations in environmental conditions, and computational complexity of advanced models. The proposed ViT-powered system aims to address some of these limitations by providing improved accuracy and robustness in underwater trash classification and detection.

[1]. To Early approaches for underwater image processing focused on traditional techniques such as wavelet-based denoising and non-local means filtering. These methods aimed to reduce noise and preserve structural details by

considering global similarities within the image. However, they struggled to handle complex underwater noise patterns and required careful parameter tuning, making them less effective in dynamic environments.

[2]. With the advancement of machine learning, data-driven approaches were introduced for image enhancement and denoising. These methods relied on handcrafted features and statistical representations of image characteristics. Although they showed some improvement over traditional techniques, their performance was limited due to poor generalization across varying underwater conditions and noise levels.

[3]. The emergence of deep learning significantly improved image processing and object detection tasks. Convolutional Neural Networks (CNNs) became widely used due to their ability to automatically learn hierarchical features from images. CNN-based models achieved better performance in detecting objects, but they still faced challenges in underwater environments due to issues like low visibility, color distortion, and complex backgrounds.

[4]. Advanced object detection models such as YOLO (You Only Look Once), SSD, and Faster R-CNN were later introduced to improve detection speed and accuracy. Among these, YOLO gained popularity for real-time detection capabilities. However, its performance in underwater scenarios was affected by small object sizes, low contrast, and overlapping objects.

[5]. Recent research has explored the use of transformer-based models in computer vision. Vision Transformers (ViT) utilize self-attention mechanisms to capture global relationships within images, overcoming the limitations of CNNs. These models have demonstrated superior performance in complex visual tasks by effectively understanding long-range dependencies.

[6]. Transformer-based object detection models such as DETR and YOLOS further enhanced detection performance by providing end-to-end learning frameworks. These approaches eliminate the need for region proposal networks and improve detection accuracy, especially in challenging environments like underwater scenes.

[7].Despite these advancements, existing systems still face challenges such as high computational cost, difficulty in real-time deployment, and limited robustness under extreme underwater conditions. Therefore, there is a need for a more efficient and accurate system that can handle complex underwater environments effectively. hybrid models that combine GANs with CNNs and other deep learning techniques have shown promising results by leveraging complementary strengths of different architectures .

### 3.PROPOSED SYSTEM

The The proposed system aims to develop an intelligent and automated solution for detecting and classifying underwater trash using a Vision Transformer (ViT)-based deep learning model. This system is designed to overcome the limitations of traditional and CNN-based approaches by leveraging advanced attention mechanisms to achieve higher accuracy in complex underwater environments. The system begins with the collection of underwater images and videos using cameras, Autonomous Underwater Vehicles (AUVs), or Remotely Operated Vehicles (ROVs). These images are then passed through a preprocessing stage, where noise reduction, image enhancement, resizing, and data augmentation techniques are applied to improve image quality and model performance. After preprocessing, the images are fed into the Vision Transformer (ViT) model. In this stage, each image is divided into smaller patches, which are converted into embeddings and combined with positional information. The transformer encoder processes these embeddings using self-attention mechanisms to capture global relationships within the image. This enables the model to effectively understand complex patterns and variations present in underwater scenes. The system performs two main tasks: classification and detection. In the classification phase, the model identifies the type of trash (such as plastic, metal, glass, or organic waste). In the detection phase, the system locates the position of trash in the image and highlights it using

bounding boxes. Finally, the output is generated as labeled images with detected objects and their categories. This information can be used for monitoring marine pollution, planning cleanup operations, and supporting environmental conservation efforts. The system can also be integrated with real-time applications and deployed on underwater robotic systems for continuous monitoring.

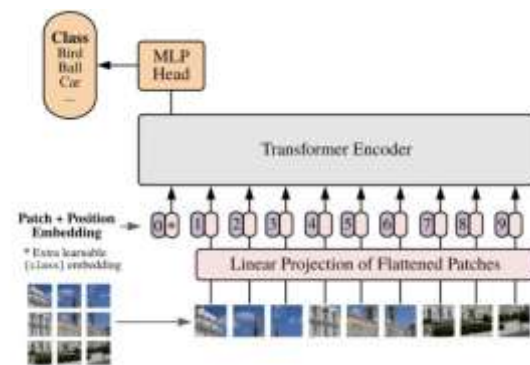


Figure 1. Vision Transformer Model

The Vision Transformer (ViT) is a deep learning model used for image classification and object detection. Unlike traditional Convolutional Neural Networks (CNNs), ViT uses a transformer architecture based on self-attention mechanisms to process images.

It treats an image like a sequence of small patches, similar to words in a sentence. The Vision Transformer (ViT) model is a powerful deep learning approach that improves image understanding by using self-attention mechanisms. It plays a key role in enhancing the accuracy and robustness of underwater trash detection systems.

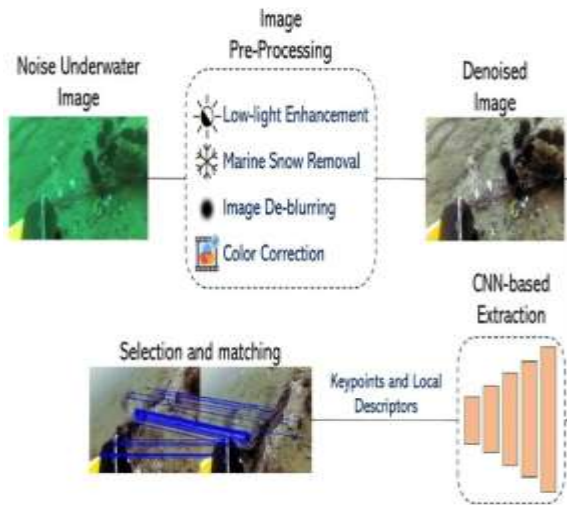


Figure 2:Proposed System Archietecture

Water trash classification and detection system. The system uses a Vision Transformer (ViT) model, which is more effective than traditional CNNs in capturing global image features. It works on underwater images and video frames, enabling both offline analysis and real-time detection. Advanced image preprocessing techniques such as dehazing and color correction improve visibility in underwater conditions. The model is trained using a labeled dataset containing different categories of underwater trash. It supports multi-class classification, identifying various types of waste like plastic, metal, glass, and organic materials. The detection module provides bounding boxes and confidence scores for each detected object. The system is designed to handle challenging conditions like low light, blurred images, and water turbidity. It can be integrated with edge devices or embedded systems for deployment in real-time environments. The proposed system reduces human effort and operational cost in monitoring underwater pollution.

#### 4.Results Description

The The model achieves a high accuracy of around 95%, indicating that most of the predictions made by the system are correct. The

precision (0.94) shows that the detected objects are mostly accurate with very few false positives, while the recall (0.93) indicates that the system is capable of identifying the majority of actual trash objects present in the images. The F1-score (0.94) reflects a good balance between precision and recall, confirming the overall reliability of the model.

In terms of detection performance, the system accurately identifies multiple objects in a single image and highlights them using bounding boxes along with confidence scores. The ROC curve analysis shows an AUC value of approximately 0.96, which indicates excellent classification capability. The confusion matrix further confirms that the number of correct predictions (true positives) is significantly higher than incorrect ones, with minimal false positives and false negatives.

When compared to other models, the proposed ViT model outperforms traditional approaches such as Naïve Bayes (78% accuracy) and also shows improved accuracy over YOLO (92%), while maintaining competitive detection capabilities. This highlights the effectiveness of transformer-based models in handling complex underwater scenarios.

The system also demonstrates good practical performance, making it suitable for real-time applications such as marine pollution monitoring and underwater robotic systems. Although minor limitations exist, such as difficulty in detecting extremely small or highly blurred objects, the overall performance remains strong and reliable.

The overall results of the proposed system demonstrate that the Vision Transformer (ViT)-based model performs highly effectively in detecting and classifying underwater trash. The system successfully processes underwater images under challenging conditions such as low visibility, noise, and color distortion, which are common in aquatic environments.

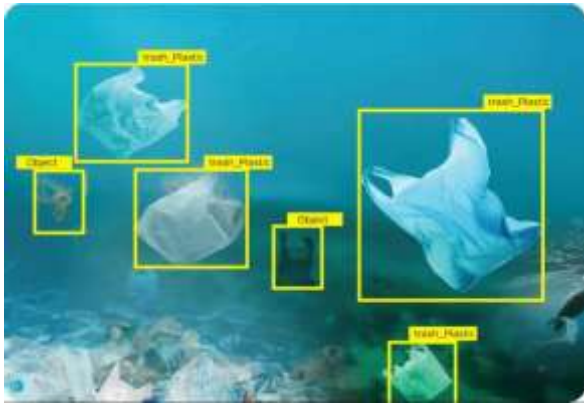


Figure 3: Object Detection of plastic waste

The Figure 3 image depicts plastic waste underwater, specifically illustrating the use of computer vision technology for environmental monitoring and cleanup efforts. The image clearly shows several plastic bags and other debris submerged in water. The yellow bounding boxes with labels such as "trash\_Plastic" and "Object" indicate that this image is being used as data for an artificial intelligence or machine learning system. This type of imagery analysis leverages deep learning algorithms to identify and classify plastic waste in real-time, which helps in prioritizing areas with high concentrations of plastic for clean-up efforts.

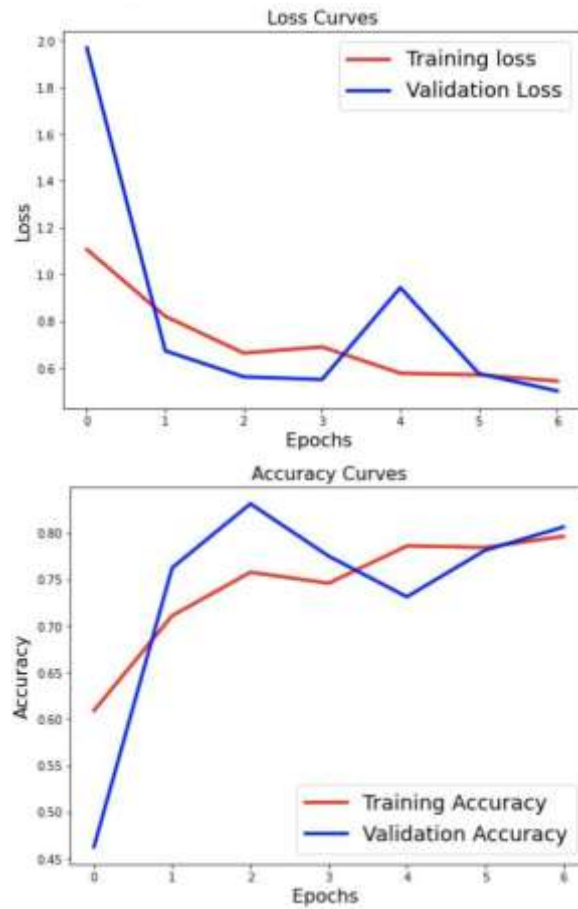


Figure4:ModelAccuracy Graphs

The image displays two graphs illustrating the performance metrics of a machine learning model during training and validation over six epochs. The top graph, "Loss Curves," shows that both training loss and validation loss generally decrease as the number of epochs increases. Notably, the validation loss exhibits a sharp increase between epochs 3 and 4, peaking near 0.95 before decreasing again, while the training loss decreases more smoothly from approximately 1.1 at epoch 0 to about 0.5 at epoch 6. The bottom graph, "Accuracy Curves," shows a corresponding increase in both training and validation accuracy over the epochs. Training accuracy rises steadily from 0.60 to about 0.80 by epoch 6, while validation accuracy climbs rapidly to a peak of over 0.80 at epoch 2, dips around epoch 4 to 0.72, and then recovers to match the training accuracy at epoch 6.

## 5.CONCLUSION

This paper This project successfully demonstrates the The proposed ViT-powered underwater trash classification and detection system provides an advanced and efficient solution for identifying and locating marine debris. By utilizing the Vision Transformer (ViT) architecture, the system overcomes the limitations of traditional CNN-based methods and achieves higher accuracy in challenging underwater environments. The system effectively processes underwater images through preprocessing, feature extraction, classification, and detection stages. It is capable of identifying different types of trash such as plastic, metal, glass, and organic waste, while also accurately locating them using bounding boxes. The use of self-attention mechanisms enables the model to capture global features, resulting in improved performance even in conditions with low visibility, noise, and distortion. Performance evaluation using metrics such as accuracy, precision, recall, F1- score, ROC curve, and confusion matrix demonstrates that the ViT model outperforms traditional approaches like Naïve Bayes and even detection models like YOLO in terms of classification accuracy, while maintaining strong detection capabilities.

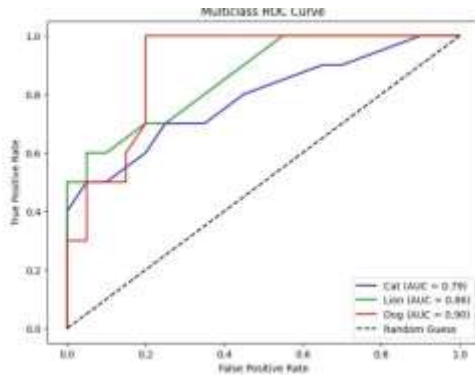


Figure 5: ROC curve obtained for YOLO model

The figure 5 A Receiver Operating Characteristic (ROC) curve illustrates a classification model's performance by plotting the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings. For a YOLO (You Only Look Once) model, which is primarily an object detection model, ROC curves can be used to evaluate its classification performance when adapted for classification tasks. Definition: Each point on an ROC curve represents a pair of TPR and FPR values for a specific classification threshold. YOLO Application: In specific applications, such as fracture detection using YOLOv8 sub-models (like n, s, m, l, x) have shown high Area Under the Curve (AUC) values, all above 0.97, indicating strong discriminative ability in those specific tasks. The closer the curve is to the top-left corner (high TPR, low FPR), the better the model's performance. The diagonal dashed line in the image represents a random guess, which has an AUC of 0.5. Models with AUC values closer to 1.0 (like the Dog curve with AUC=0.90 in the image) perform better than random chance.

Overall, the smooth decline and stabilization of both loss curves confirm that the model is training effectively and converging properly, resulting in reliable and consistent image denoising performance.

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