An Automatic Detection of River Garbage Using 360-degree Camera

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[論文]

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Ryota Nakamura

Abstract

Ocean plastic garbage is partly caused by the influx of garbage from rivers. Plastic pollution is a critical environmental issue today, but there remains a gap in information regarding the local distribution of plastics, which is essential for preventing adverse effects and developing mitigation measures. Traditionally, government agencies and volunteer groups have conducted river walks to monitor illegal dumping of garbage; however, this approach is costly, time-consuming, and insufficiently frequent for monitoring the highly fluid nature of river garbage. While there are studies that involve monitoring garbage using cameras installed on bridges and manual photography at fixed points during volunteer activities, it is challenging to ascertain the status of garbage before it washes ashore, and there are concerns about the sustainability of such photography efforts. Consequently, the objective of this study is to develop a system that enables the collection of garbage dumping status by taking pictures with a 360-degree camera while enjoying the activity itself. In this paper, we present an overview of the Immersive Multi-dimensional Data Visualization System and investigate its potential for detecting plastic waste in 360-degree panoramic images. We also provide our verification results on the capability of a 360-degree camera to automatically detect garbage in rivers.

1. Introduction

Plastic, a versatile and affordable material, has seen a 20-fold increase in usage over the past 50 years, and is expected to double further within the next two decades. However, over 150 million tons of plastic waste are generated annually, with at least 10 million tons ending up in the ocean, potentially surpassing the number of fish in the sea by 2050 [1]. Without improvements in plastic waste management, the amount of plastic entering the ocean could increase by an order of magnitude within a decade [2]. Plastic pollution is a global issue that harms the natural environment, ecosystems, marine resources, and human health. Most marine plastic debris originates from rivers,

as plastic waste is transported from inland areas, such as urban regions, to the ocean via rivers [3]-[5]. Approximately 90% of marine plastic debris is reported to come from just 10 rivers [6]. Therefore, collecting river garbage can significantly contribute to reducing marine plastic waste. Efforts have been made to use robots for garbage detection and collection; however, most of these initiatives target floating debris in waterways and do not address garbage scattered on riverbeds and breakwaters before it drifts away. As depicted in Figure 1, the ground surrounding waterways is often strewn with plastic and paper waste, which eventually enters the water due to rising water levels or strong winds. Some government agencies and volunteer groups have conducted fixed-point monitoring of garbage dumping and scattering [7], but these efforts are expensive and unsustainable. In Japan, an online "garbage map" offers a comprehensive view of illegal dumping and littering in first-class rivers. This map presents cases of unlawful waste disposal detected by administrative agencies during routine river patrols. Additionally, the map is employed for expedited garbage collection. Nonetheless, patrols are carried out year-round to observe and record the status of garbage dumping, resulting in a resource-intensive and expensive process. Popular outdoor activities near rivers include walking, cycling, and mountain biking. In this study, we explore a method that allows users to engage in these activities while simultaneously capturing footage of garbage dumping and littering in rivers using a 360-degree video camera. For example, this approach enables users to observe river garbage dumping and littering while riding off-road along riverbeds on a mountain bike equipped with a 360-degree video camera. The data collected through this method can be visualized on a multi-user 3D web platform called the "Immersive Multi-dimensional Data Visualization System," which we have developed. This paper provides an overview of the Immersive Multi-dimensional Data Visualization System and examines its potential for detecting plastic waste in 360-degree panoramic images.

Fig. 1 An example of garbage scattered in the river (photo taken with a 360° camera)

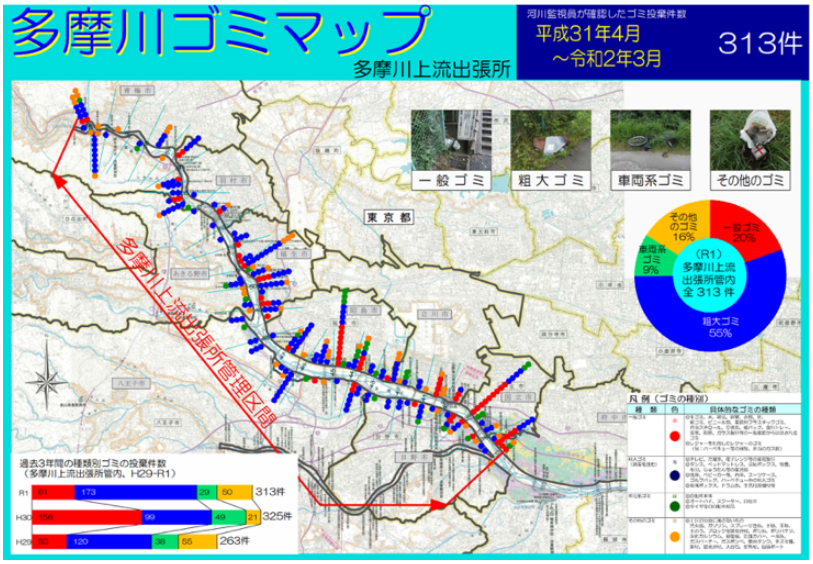

Fig.2 An example of river garbage map (April 2018 - March 2020: in the jurisdiction of Tama River Upstream Sub-branch Office, Ministry of Land, Infrastructure, Transport and Tourism, https://www.ktr.mlit.go.jp/ktr_content/content/000797310.pdf (March 7, 2022, Access)

2. Related works

Sea turtles are endangered because they often eat marine plastic waste, which resembles jellyfish in shape, texture, and color, and their existence needs to be protected and preserved. Therefore, a method was proposed that can recognize two

different objects, a plastic bottle and a plastic bag, using the Faster R-CNN algorithm. Experimental results showed that the plastic object and the plastic bottle can be correctly recognized using normal images, especially without using image processing to change hue and tone[8] Other attempts have been made to recognize plastic garbage on beaches by image classification using convolutional neural networks and transition learning. As a result of learning a large number of images of clean and polluted beaches, plastic garbage could be recognized with high accuracy[9]. These papers employ various computer vision techniques, such as convolutional neural networks and object detection models, to detect discarded plastic bottles in public spaces. The research aims to improve the efficiency and effectiveness of garbage collection and environmental monitoring efforts, which can have a significant impact on the environment and human health. The papers focus on a range of applications, from beach cleaning to urban public spaces, and use different types of sensors and data sources, such as drone images and depth data. There is also an attempt to automatically classify the types of plastic garbage. A system has been developed to automatically classify them into four types: PET, PP, HDPE, and LDPE, which can be recycled as polyester material[10] (PP: polypropylene, HDPE: high density polyethylene, LDPE: low density polyethylene). The prevalence of garbage dispersion varies according to seasonal and climatic conditions. Some waste may become dislodged from refuse collection sites near rivers, carried away by wind, or deposited into waterways due to natural disasters such as river floods or typhoons. Numerous examples exist of robotic development for automating garbage detection and collection, specifically targeting floating debris in waterways [8]-[11]. For instance, the robot described in [12] is equipped with a camera module and an ultrasonic sensor for detecting floating debris while traversing the water surface. It employs image recognition technology for highly accurate detection and collection of debris, while also focusing on reducing energy consumption by optimizing the collection route. Many of these examples utilize convolutional neural networks (CNN) and real-time object detection algorithms, such as YOLOv3 [13]-[15]. A garbage collection robot designed to operate on lawns has also been developed [16]. This robot accurately and autonomously detects garbage using deep learning for recognition, and optimizes its navigation through ground segmentation using deep learning. Experimental results demonstrate a garbage recognition accuracy of 95% and improved cleaning efficiency due to the navigation optimization method. Other studies have explored robots for automatic collection of underwater debris, aimed at cleaning swimming pools and investigating oceanic debris [17]-[19]. In Japan, an online ″garbage map″ offers a comprehensive view of illegal dumping and littering in first-class rivers. This map presents cases of unlawful waste disposal detected by administrative

agencies during routine river patrols. Additionally, the map is employed for expedited garbage collection. Nonetheless, patrols are carried out year-round to observe and record the status of garbage dumping, resulting in a resource-intensive and expensive process.

3. Immersive Multi-dimensional Data Visualization System

As illustrated in Fig. 3, we are developing a web-based system to assess the status of garbage dumping in rivers and facilitate discussions regarding waste collection plans. The client-side of the system is built using HTML and A-Frame, a JavaScript library, while the server-side employs Node.js and Socket.IO to create a multi-user WebXR. This system can be accessed from a PC, tablet, or smartphone at any time and place, provided there is an internet connection. The column graph in Fig. 3 displays the location, type, and quantity of garbage derived from the existing garbage map, with the transparent graph indicating the locations of waste dumping. The transparency represents the year of the collected data, with higher transparency indicating older data. Red columns signify general waste (food waste, paper waste, plastic waste, etc.), blue represents bulky waste (TVs, refrigerators, microwave ovens, bed mattresses, etc.), green indicates vehicular waste (car bodies, motorcycles, bicycles, etc.), and yellow denotes other waste (earth, sand, blocks, and other construction waste materials). The system provides communication support to help users understand the waste dumping status and collection plans while freely navigating the space as if flying like a bird. Moreover, by clicking on the sphere in Fig. 3, users can immerse themselves in a space featuring a 360-degree panoramic photograph taken at that location, allowing them to inspect the actual garbage dumping situation.

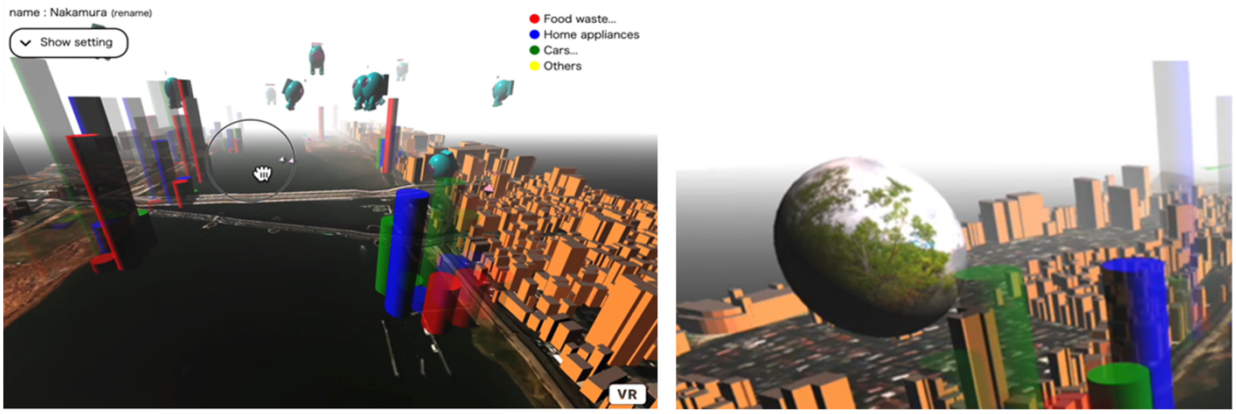

Fig. 3 Immersive Multi-dimensional Data Visualization System

(The left figure shows multiple people examining the garbage scattering situation in a river. The right figure represents the entry point to the 360-degree panoramic image of the site.)

4. Garbage Detection Method using 360-degree camera

The workflow of the proposed method is shown in Figure 4. The proposed method aims to gather data by unintentionally recording instances of garbage dumping in rivers by users who enjoy walking or cycling near these waterways. For example, as depicted in the left panel of Figure 5, a bicycle equipped with a 360-degree action camera captures video footage while riding in the P2 area, shown on the right panel of Figure 5. Users only need to press the camera's record button at the beginning of their journey, with no requirement to stop and take photos when encountering garbage. Once the cycling session is complete, the service provider transfers the camera's video files to a computer. The proposed tool's automatic processing program extracts 360-degree panoramic images from the 360-degree video for each specified frame. The panoramic images are then divided into smaller image blocks, and plastic waste is detected using a fine-tuned object detection model. Additionally, metadata such as latitude and longitude attached to the images are extracted. Based on the number of plastic debris instances detected in the 360-degree panoramic images from the same location, data on the locations and quantities of scattered plastic waste are uploaded to the Immersive Multidimensional Data Visualization System.

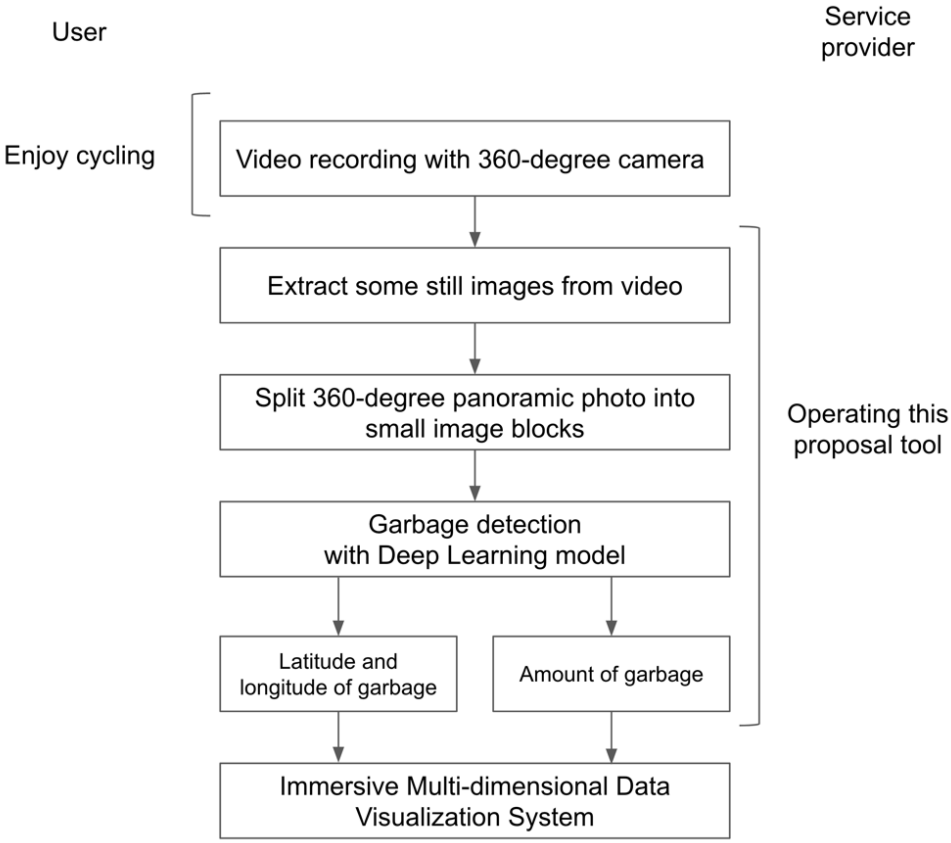

Fig. 4 Schematic representation of the proposed approach

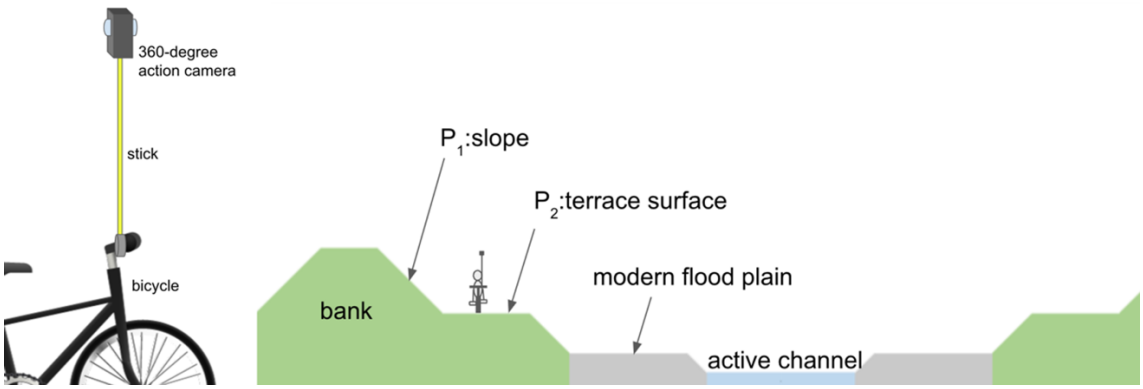

Fig. 5 360-degree action camera mounting setup and location of bicycles along the river.

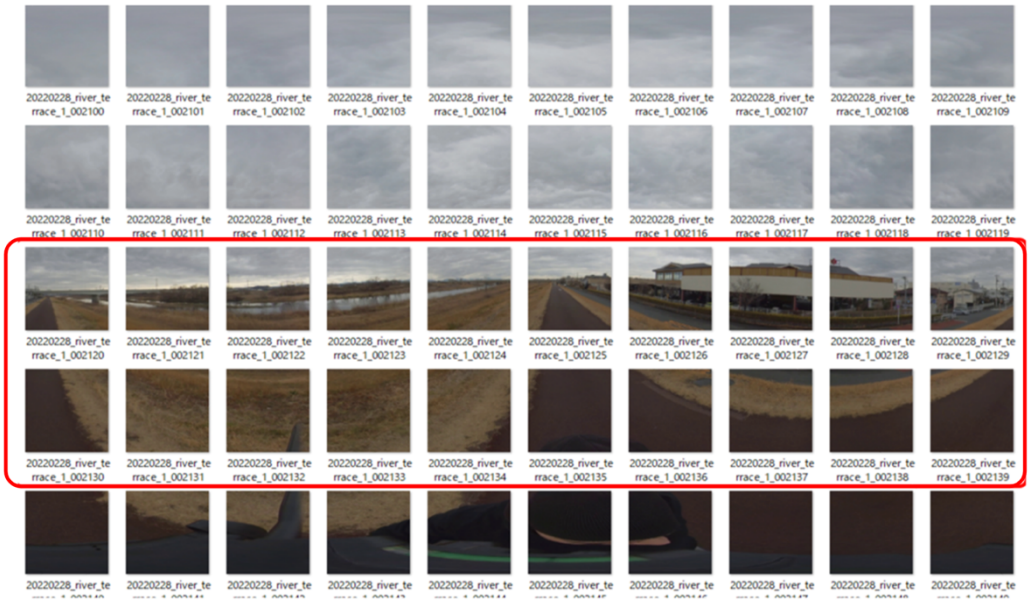

Fig. 6 Example of Segmented 360-Degree Panoramic Photo for Object Detection and Plastic Waste Detection Area

The 360-degree panoramic video captured by our tool using a 360-degree action camera extracts images at regular intervals. These images are divided into small image blocks, as shown in Figure 6. Depending on the location of the 360-degree action camera, the sky is often captured in the first or second row from the top in Figure 6, and these images are excluded from object detection. Likewise, the bottom row in Figure 6 often contains the user, so this row is also excluded from object detection. While there may be concerns that plastic waste could appear at the left and right edges of the bottom row, this is not an issue, as the waste is likely to appear in the third and fourth rows from the top in Figure 6 if the frequency of photo extraction from the video is high. By narrowing down the objects to be detected as described above, the goal is to reduce computational cost and false positives.

5. Experiments and results

An experiment was conducted under the following conditions to determine the extent to which plastic waste discarded in rivers could be detected simply by recording video with a 360-degree camera while enjoying a walk:

Experiment date: February 28, 2022 (weather: cloudy)

Experiment location: Tama River in Fuchu City, Tokyo, Japan

Number of experiment participants: 1 person

Shooting method:

- Walking along the paved river top (P2 in Figure 2)
- Using a selfie stick, camera was positioned approximately 2 m above the ground
- Shooting time: 31 minutes 27 seconds, walking distance: approx. 3 km (walking speed: approx. 5.7 km/h)
- Video file capacity: 37.2 GB (recorded on a microSD 64 GB)
- Hardware: Insta360 ONE X (continuous shooting time: up to 60 minutes), exposure mode: automatic, white balance: automatic, frame rate: 25 fps, resolution: 5,780 x 2,880 pixels.
- Software: Converted from insv format to mp4 format using Insta360 Studio2021

Creating the dataset:

- The developed tool automatically divides a 360-degree panoramic photo into 10 horizontal and 5 vertical segments (split image: 576 x 576 pixels, file size per segment: tens to hundreds of kB).
- To exclude the sky and the photographer's area, only the images in the third and fourth rows from the top in Figure 6 are included.
- Annotation was performed using Microsoft Vott 2.2.0.

Model Creation:

We utilized YOLOv3 for learning to detect plastic garbage under the following conditions:

- Input image size: 608 x 608[pixel]
- Number of training epochs: 10,000
- Batch size: 32, confidence threshold: 0.5, NMS threshold: 0.45
- Learning rate: 0.001, momentum: 0.9, decay: 0.0005
- Data augmentation: random size: True, left-right flip: True, distortion: True, random placing: True, jitter: 0.3
- The existing model, "YOLOv3," was trained using transfer learning, and garbage detection training was conducted under the following conditions:

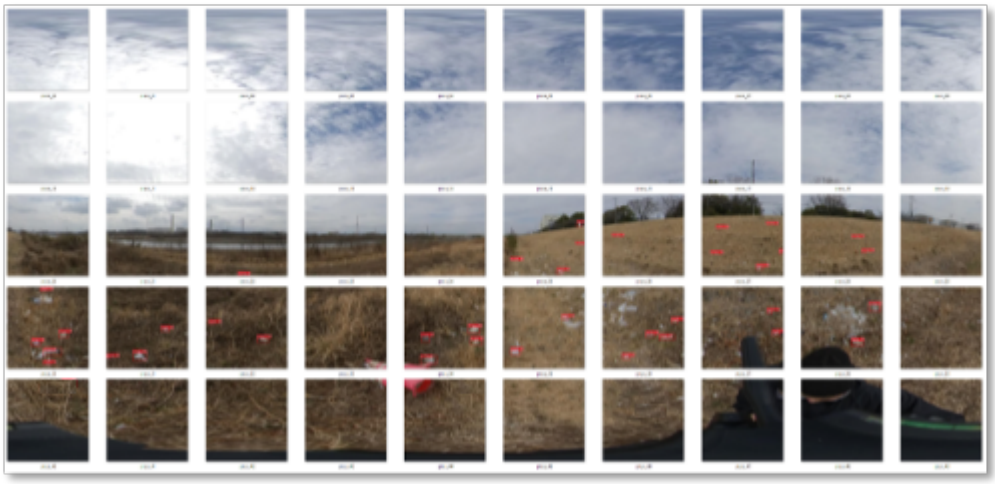

Fig. 7 Example of plastic waste detection in rivers using the proposed method

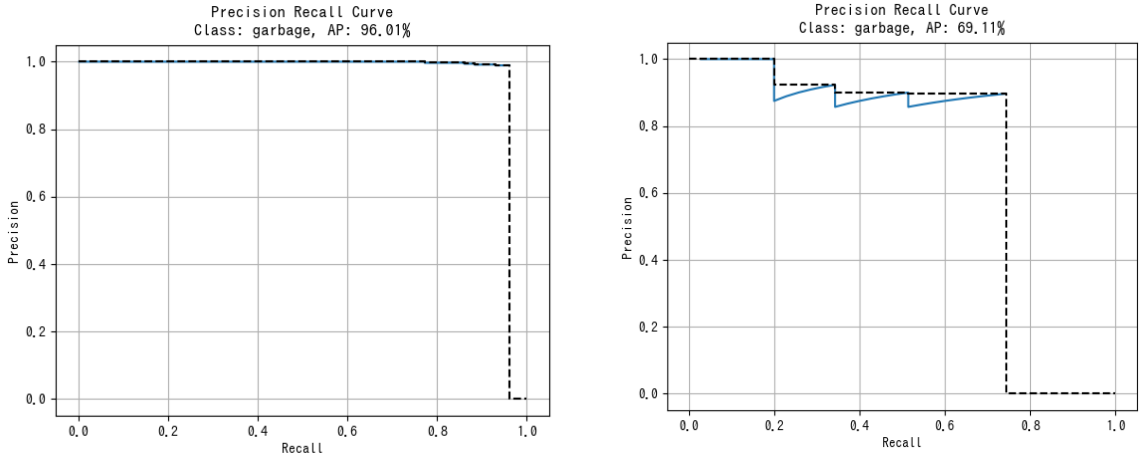

Fig. 8 Example of Segmented 360-Degree Panoramic Photo for Object Detection and Plastic Waste Detection Area

Fig. 9 Example of plastic waste detection in rivers using the proposed method

Figure 7 presents an example of the results obtained when applying the proposed method to detect plastic waste in a 360-degree panoramic photograph. It demonstrates that the method is capable of identifying plastic waste within the panoramic image. As depicted in the left panel of Figure 8, the prediction accuracy for the training data reached a high level of 96.01%, indicating that the learning process progressed smoothly for the data used to train the object detection model. However, the accuracy on the validation data was considerably lower (69.11%) than that of the training data, suggesting that overfitting occurred, resulting in a decline in the model's generalization performance. The bottom row of Figure 9 illustrates instances where plastic waste was not detected. While the detection of garbage such as plastic bottles was relatively accurate, there were notable omissions in detecting thin and transparent waste, like plastic bags. To address this issue, there are plans to increase the training data and implement models with higher detection accuracy, such as Faster R-CNN or DETR.

6. Conclusion

This paper presents an overview of the "Immersive Multidimensional Data Visualization System" and explores its potential for detecting plastic waste from 360-degree panoramic video images. The results indicate the possibility of identifying plastic waste in rivers with relatively high accuracy using a 360-degree action camera; this can be achieved by extracting panoramic images from 360-degree videos and then employing small image blocks for object detection. However, given the numerous detection omissions, it is essential to increase the image data and further train the model.

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