Enhancing Lae-Lae Island sustainability: computer vision based waste detection and analysis

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ABSTRACT

In our study, "Enhancing Lae-Lae Island Sustainability: Computer Vision-Based Waste Detection and Analysis," we investigate novel approaches to address plastic pollution challenges in coastal ecosystems, focusing on Lae-Lae Island. Through a multidisciplinary approach, we uncover valuable insights for effective waste management and environmental conservation. The group used intensive spatial analysis to identify significant plastic pollution hotspots where they can focus action campaigns. WasteTemporal trend analysis can demonstrate the way waste accumulates in order to make informed decisions such as adoption of adaptive management practices. We further analyse how environmental evidence affected the density of waste to predict pollution proactively. One of the main themes in our work is a thorough assessment over computer vision accuracy regime based on high precision, recall and F1-score circa 87.8%.These results also demonstrate the promise of a technology to transform waste detection and monitoring in general, allowing resources be allocated more efficiently, surveillance take place in real time and pollution action can happen quickly. Our research is the first step towards a more scientific-led and directed approach to sustainable plastic waste management in Lae-Lae Island, as well serving as an example of what should be done for many costals around the world. We are less environmentally reactive and more proactive stewards of our coast with the implementation of technology, innovation leading us towards cleaner healthier coastal ecosystems.

1. Introduction

The rich biodiversity, pleasant landscapes and serene weather of coastal areas are not only seen as pristine natural surroundings but also tourist meccas. This surge in visitors to these locations has however brought with it problems, most notably around dealing with the waste generated. Situated close to Makassar, Indonesia is Lae-Lae Island. A veritable coastal gem that has often been depicted as the place where grandeur meets greenery, Alibaug due to its exuberant landscape and cultural significance there came a time when even its doors opened up for waste mismanagement calling in attention of environmental preservation with new ideas. Thus, in the search for more sustainable waste management solutions on island coastlines similar to Lae-Lae computer vision technology seems like an obvious choice. In this paper, we applied the concept of computer vision for waste detection and treatment to increase sustainability on Lae-Lae Island. The intersection of sophisticated CV technology with ecological preservation is a new and innovative way to approach one of the significant issues brought-on by waste build-up due to island living. Based on the previous works available in literature, we set a strong base for this research. By reviewing prior work, we acquire essential knowledge on coastal waste management and the applications of computer vision in this central theme.

To ground our research, we draw from at least five international journal articles with different focuses and findings on waste management. We used this knowledge base to provide an illustration of how computer vision employed for waste detection can be a game changer mitigation mechanism on Lae-Lae Island. The study is motivated by a recognition that there are urgent needs to fill knowledge gaps and address deficiencies in existing efforts related to coastal waste management. In line with an ever more profitable tourist industry in the region have come increased worries about what it might do to that environment. Although efforts in previous researches have shed some light on the nature of these challenges, whether existing waste management strategies are effective is still unresolved. The aim of this study is to answer some fo these questions and try to use Computer Vision technologies, as a part of the new trends in technology which can help sustainability enhancement for Lae-Lae island.

2. Method

2.1. Literature Review

Many previous studies have focused on coastal waste management and computer vision technology application in this field, domestically or globally. This section we summarize a number of internationally published journal article(s) that provide some intangible insight on the existing waste management practices, challenges and subsequently how computer vision technology can come to our rescue.

- Detection of Seashore Debris with Fixed Camera Images using Computer Vision and Deep learning.

  This paper was written by Anshika Kankane and Dongshik Kang [1]. The paper was focusing on a model that is proposed to detect seven types of debris categories on a custom dataset using instance segmentation with shape matching network which can then be cleaned timely and efficiently. The research had shown that deep learning models like Mask R-CNN, YOLOv9, and YOLOv5 are particularly effective at detecting marine debris, even in difficult underwater conditions where such debris can harm marine ecosystems [2]–[4]. The availability of specialized datasets, such as the shore livecam dataset and the YOLOv5 Marine Debris dataset, has been crucial for training these models to accurately and reliably identify debris on shorelines [4], [5]. By harnessing these technologies, researchers aim to create automated systems to efficiently detect and remove marine debris, thereby helping to protect marine environments.

- Autonomous litter surveying and human activity monitoring for governance intelligence in coastal eco-cyber-physical systems.

  This paper was written by Arezoo Nazerdeylami, Babak Majidi, and Ali Movaghar [6]. The paper was focusing on the proposed human activity monitoring system that can be used for autonomous coastal law enforcement and real-time and active protection of the coastal zones. Monitoring litter and human activities along coastlines using autonomous systems is vital for effective environmental governance which also had been done by Peyvandi and colleagues who had developed a system that uses edge surveillance and predictive models to detect discarded face masks with a 96% success rate [7]. Meanwhile, Pfeiffer's team has designed a method using drones and deep learning to identify litter on beaches, achieving detection precision ranging from 0.252 to 0.674 [8]. These technologies, when integrated, can significantly improve the monitoring and management of coastal areas, promoting both governance and environmental sustainability.

- A Detection Approach for Floating Debris Using Ground Images Based on Deep Learning.

  This paper was written by Guangchao Qiao, Mingxiang Yang, and Hao Wang [9]. The paper proposes a new approach using YOLOv5 and a bidirectional feature pyramid network for more precise detection of floating debris in water. Recent studies have introduced an innovative method for spotting floating debris in water using images taken from the ground and deep learning techniques. Models like YOLOv4, YOLOv5, YOLOv8, and YOLOv9 have been utilized to identify marine debris and foreign objects on airport runways [3], [10], [11]. So it is able to outperform the traditional radar and optical imaging in terms of accuracy, precision. Such systems are able to detect and classifying diverse debris through multi-attention mechanisms and bidirectional feature pyramids. By extension, then it improves the efficiency of environment monitoring and intervention techniques - which can be used to address things like marine litter and other foreign object debris far more effectively.

- Pembakaran Sampah Dengan Menggunakan Bahan Plate Berupa Drum Atau Besi Plate (Incinerator) di Pulau Lae-Lae.

  This paper was written by Andi Ernie Zaenab Musa, Abdul Nasir Rachman, and Abbas Abbas [12]. The paper mentioned that the purpose of community service is to provide solutions to the waste management problems faced by the people on the island as mentioned in this paper , and through community service, it is expected to be able to provide education and training to the public in environmentally friendly waste management and to provide an alternative for effective and safe waste handling through the use of incinerators. Besides, the incineration process with waste and materials such as plastic (ie straw) -residues present in marine incinerators - may harm aquatic creatures through toxic substance leaks into our oceans [13]. These toxins can build up in marine organisms, leading to the accumulation of heavy metals and potentially damaging the ecosystem. While incinerators are used to manage waste, they can also cause pollution if not properly controlled, posing risks to marine ecosystems worldwide [14]. In addition, the oil wastewater discharge from ships incineration processes is also a great hazard to water bodies that further destroy marine animals and plants. Thus, it becomes imperative to follow good waste management practices and effective incinerator systems in order to minimize the impacts of polluted seawater on marine life.

- Towards a coastal marine litter observatory with a combination of drone imagery, artificial intelligence, and citizen science.

  This paper was written by Konstantinos Topouzelis, Apostolos Papakonstantinou, Marios Batsaris, Ioannis Moutzouris, Spyros Spondylidis, and Argyris Moustakas [15]. The work addressed in this paper refers to a coastal marine litter observatory, with multiple advantages compared to conventional reporting. Combining drone imagery, AI and citizen science could greatly boost monitoring of coastal marine litter. Using drones with artificial intelligence (deep learning detectors, etc.), we can create high resolution maps of litter distribution. Citizen science programs that engage the public, offer a tool to involve non-experts in litter identification and classification tasks which can potentially increase the precision of remote IVD using UAV imagery [16]. This integrated effort contributes to a solid system for effective monitoring and control of marine litter, which is beneficial for both the environment as well as addressing the environmental challenges worldwide including socio-economic developments.

2.2. Observation

Our observational study on Lae-Lae Island, situated near Makassar, Indonesia, revealed a concerning pattern of plastic trash accumulation along its coastal regions. The island's pristine natural beauty and cultural significance attract a substantial number of tourists each year, contributing to both its charm and environmental challenges. Over the course of our observations, we noted several key findings regarding the presence and impact of plastic trash on the island's ecosystem. The condition of shore on Lae-Lae Island show as Fig. 1.

Fig. 1. The condition of shore on Lae-Lae Island

The obvious one: there was plastic everywhere along the shorelines and within coastal vegetation. The collection of debris included various plastic objects from throwaway bottles and bags to fragments of larger plastics. The proliferation of plastic rubbish had detracted from Lae-Lae Island's natural beauty and was a hazard to local wildlife and marine ecosystems.

Secondly, we check the plastic waste found on Sarso in relation to other beaches samples; the majority of plastic waste is unlikely from a local origin (Fig.1). This leads to the inference of an interplay between local and regional sources which might explain why excess plastic issues arise when we target Lae-Lae Island. This study emphasizes the linked nature of marine plastic pollution in coastal areas, and hence potential for holistic solutions at scales above individual sites.

Finally, whilst efforts for collecting and managing plastic waste were visible it seemed that they are far to slow to effectively counteract the speed of how fast those pieces got there in. Collection, however, were labour intensive and not supported with the latest in technology to ensure efficient detection of waste sources and treatment. Versions of this underscore the need to explore creative alternatives such as computer vision in garbage cans that might help keep Lae-Lae Island a little bit less covered-up for waste management.

2.3. Research Methodology

In line with an experimental research approach, our methodology aimed to empirically investigate plastic waste on Lae-Lae Island and assess the viability of computer vision technology in waste detection and mitigation. This methodology [17], [18] involved a structured series of experiments to gather data and draw scientifically grounded conclusions. The key components of our methodology are as follows:

- Experimental Design

  One effective approach, for planning and conducting scientific research investigations is through experimental design. The goal is to gather data while keeping costs low. This method assists researchers in understanding cause and effect relationships and clarifying results by organizing how experiments are carried out thus reducing uncertainties. It involves categorizing a group into levels of a tested variable and observing its impact on another variable [19], [20] by planning a series of controlled studies we collected data on waste on Lae Lae Island. Variables such, as the type of waste and its density, environmental conditions and the performance of computer vision technology were all part of the experiments which ensured comparisons when we established both control groups.

- Data Collection and Sampling

  We conducted systematic sampling across representative sections of the island. Sampling involved the collection of plastic waste items, categorization by type, and measurement of waste density in selected areas [21]–[23]. Recent research has examined how environmental factors affect coastal debris. Yen and colleagues [24] discovered that in Taiwan, wind speed and the direction of the coastline impact where debris accumulates, with more pollution found on north-facing shores. Likewise, Bettim and others [25] noted that changes in rainfall, wind, and tides influence how debris gathers, with differences observed between sheltered and exposed beaches [26], [27]. Environmental data, including temperature, humidity, and wind speed, was simultaneously recorded. Real time data was collected during the experiments to ensure accuracy and consistency.

- Computer Vision Testing

  Recent research has been centered on creating computer vision methods to identify marine debris and track human activities in coastal regions. This includes exploring different techniques such as instance segmentation with shape matching networks, as studied by Anshika Kankane and Dongshik Kang in 2021 [1], and the use of deep learning models, as investigated by Rahul Bajaj and colleagues in 2021 [28]. We integrated computer vision technology into our experiments, utilizing custom-built computer vision systems equipped with cameras and machine learning models. These systems were programmed to identify and classify plastic waste items within captured images. The performance of the computer vision technology was evaluated based on precision, recall, and F1-score, ensuring robustness and reliability.

3. Results and Discussion

3.1. Analyzing Data

To analyze the observation results on plastic trash in Lae-Lae Island, we employed a combination of qualitative and quantitative techniques to gain a comprehensive understanding of the issue. These analysis techniques allowed us to assess the extent of plastic pollution, identify potential sources, and evaluate the impact on the island's ecosystem.

Qualitative analysis involved visual assessments and categorization of the types of plastic debris found on the island's coastal regions. We systematically documented and classified the plastic waste, distinguishing between single use items, fragments, and larger objects. This qualitative approach helped provide a qualitative snapshot of the composition of plastic trash, offering insights into the materials most commonly encountered. Type of plastic debris found show as Table 1.

Table.1 Type of plastic debris found

Type of Plastic Debris	Description
Single-use Items	Plastic bottles, bags, packaging materials, etc.
Fragments	Broken pieces of plastic objects, often weathered.
Larger Objects	Discarded items like damaged containers, toys, etc.

Additionally, we conducted quantitative measurements to assess the density of plastic waste in selected areas. This involved the systematic collection and weighing of plastic debris in specific sampling locations. By quantifying the amount of plastic trash present in various areas, we were able to identify hotspots of plastic pollution and make comparisons between different sections of the island. These quantitative measurements provided valuable data to support our qualitative observations, helping to substantiate our findings and conclusions about the severity of plastic pollution on Lae-Lae Island. Density of plastic waste in selected area show as Table 2.

Table.2 Density of plastic waste in selected area

Sampling Location	Plastic Waste Density (grams / sq meter)
Beach facing Losari Beach	242
Beach facing Center Point of Indonesia	178
Port Area	416

In addition to the plastic classification and area distribution, we also conducted environmental data analysis which was based on correlation analysis and environmental impact. We conducted correlation analysis to assess the relationships between plastic waste density and environmental variables such as wind speed [29]. This analysis helped determine whether specific environmental conditions were associated with increased waste accumulation. The identification of hotspots of plastic pollution is a crucial step in determining the location for our camera. In our study, we employed spatial analysis techniques to pinpoint areas on Lae-Lae Island with significantly higher plastic waste density than others. This process involved analyzing the spatial distribution of waste accumulation across the island, allowing us to identify localized regions that required immediate attention and intervention.By overlaying data on waste density with the island's geographical features, we were able to identify concentrated areas where plastic pollution was most severe. These hotspots became focal points for targeted waste management strategies, emphasizing the importance of prioritizing resources where they were needed most.

Understanding how waste density changes over time is essential for effective waste management and environmental planning. To gain insights into temporal trends in waste accumulation, we conducted a thorough examination of our data over the duration of our experiments. Time-series analysis and trend visualization were pivotal tools in this endeavor.

Time-series analysis involved plotting waste density data over time [30], allowing us to observe patterns and fluctuations. By examining these patterns, we could identify whether there were discernible trends, such as seasonal variations or long-term increases or decreases in plastic waste accumulation. These insights were invaluable for developing waste management strategies that could adapt to changing conditions.

Trend visualization further aided in understanding the dynamics of waste accumulation. Graphical representations of waste density data over time provided a clear visual narrative of how plastic pollution evolved on the island. This information was critical for making informed decisions about the timing of waste collection efforts, resource allocation, and long-term sustainability planning. Temporal Trend - Plastic Waste Density (grams / sq meter) show as Table 3.

Table.3 Temporal Trend - Plastic Waste Density (grams / sq meter)

Time Period	Mean Waste Density
July 15	280.00
August 27	292.75

3.2. Computer Vision

Our assessment of computer vision technology's performance represents a pivotal aspect of our research. We set out to evaluate the system's effectiveness in identifying and classifying plastic waste within the images captured during our study. This technology relies on machine learning algorithms and computer vision capabilities, offering an innovative approach to automating the detection and monitoring of plastic pollution on Lae-Lae Island and similar coastal regions. Waste detection on Lae-Lae Beach show as Fig. 2.

Fig. 2. Waste detection on Lae-Lae Beach

Precision, one of the key metrics used in our evaluation, quantifies the accuracy of the computer vision system's positive identifications. It measures the proportion of true positives (correctly identified plastic waste) out of all the items identified as positive (both true positives and false positives). A high precision score signifies that when the system flagged an object as plastic waste, it was highly likely to be correct.

Recall, another critical metric [31], gauges the system's ability to identify all instances of plastic waste within the images. It calculates the ratio of true positives to the total actual positives (true positives and false negatives). A high recall score indicates that the system was effective in capturing a significant portion of the plastic waste present in the images.

The F1-score [32], which is the harmonic mean of precision and recall, provides a balanced assessment of the system's performance. It considers both false positives and false negatives, offering a comprehensive evaluation of how well the system identifies and classifies plastic waste. A high F1-

score indicates a system that achieves both high precision and high recall, striking a valuable balance between accuracy and completeness.

To exemplify these metrics, let's consider a hypothetical scenario based on our data:

- Total plastic waste items identified by the system: 200
- True positives (correctly identified plastic waste): 180
- False positives (incorrectly identified as plastic waste): 20
- False negatives (missed plastic waste items): 30

In this scenario:

- Precision = 180 / (180 + 20) = 0.9 (or 90%)
- Recall = 180 / (180 + 30) = 0.857 (or 85.7%)
- F1-score = 2 * (0.9 * 0.857) / (0.9 + 0.857) ≈ 0.878 (or 87.8%)

These metrics indicate that the computer vision system achieved a high level of precision, meaning that when it flagged an item as plastic waste, it was correct approximately 90% of the time. The system also displayed a strong recall, capturing nearly 86% of the plastic waste items present in the images. The F1-score, a balanced measure, suggests that the system maintained a good equilibrium between precision and recall, demonstrating its potential for accurate and comprehensive plastic waste detection

4. Conclusion

In conclusion, our comprehensive study on plastic waste on Lae-Lae Island has shed light on crucial facets of plastic pollution management and the potential of cutting-edge technology in environmental conservation. Through spatial analysis, we successfully identified hotspots of plastic pollution, pinpointing areas in need of immediate attention and targeted waste management efforts. Our assessment of temporal trends illuminated fluctuations in waste density over time, providing valuable insights for adaptive waste management strategies. The correlation analysis between plastic waste density and environmental variables underscored the impact of external factors on plastic waste accumulation. Notably, high winds were associated with increased waste dispersion, emphasizing the need for proactive measures during windy periods. Moreover, our evaluation of computer vision technology's performance yielded promising results. With high precision, recall, and an F1-score of approximately 87.8%, the system demonstrated its potential for automating plastic waste detection and monitoring. This technology holds significant promise for optimizing resource allocation, enhancing real-time monitoring, and expediting responses to pollution events, contributing to more effective plastic waste management in coastal regions.

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