Safeguarding the Marine and Coastal Environment with Artificial Intelligence

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Abstract
Coastal and marine ecosystems face ongoing threats from both human activities and natural processes. Human intervention over the past century has disrupted coastal equilibrium, leading to irreversible phenomena. The unchecked release of plastic waste, for example, further compounds these challenges, posing a severe threat to marine life, the health of our seas. In these last years, the CVPR, CI&SS, and HPSC Labs, associated with the interdisciplinary Lab Neptun-IA at the University of Napoli Parthenope's Department of Science and Technology, have embarked on initiatives to address beach and undersea litter detection and recognition. Leveraging Artificial Intelligence and Computer Vision technologies, these efforts aim to develop innovative solutions for monitoring, identifying and managing marine areas, offering promising pathways towards mitigating the impacts of human-induced environmental degradation on coastal and marine ecosystems.

Keywords
Undersea and Beach litter, Litter recognition, Object detection, Instance segmentation, Aerial and marine drone, Smart rover, Deep optical flow, Digital twin

1. Introduction

Recent reports [1], [2] emphasize how human activity has disrupted coastal balance, exacerbating or even initiating irreversible erosion processes and leading to the intrusion of salt wedges into regions where agricultural productivity is vital to the local economy. Moreover, in recent years, several international reports by the *IPCC*[1] have emphasized the importance of developing economic models that are less dependent on fossil fuels. The latter is primarily responsible for rising temperatures on a global scale, which in turn are responsible for rising sea levels. In the near future, entire coastal belts may be permanently invaded by the sea [3]. In addition to these processes of physical imbalance, there are, unfortunately, those related to the overexploitation of sandy shores, with the consequent alteration of the beach environment, and sometimes to the disfigurement of the maritime territory, with the consequent loss of landscape and economic value. In particular, the uncontrolled release of large quantities of plastic material into the environment is increasingly threatening our seas and the marine organisms that live in them. Many of these issues are discussed and supported by many relevant national and international bodies and organs, within the European Community, which seems to be strongly committed to raising awareness of the above issues. To mention some of these bodies, among the most important are the MedECC (Mediterranean Experts on Climate and Environmental Change) [4], regional sea conventions (OSPAR Commission, Barcelona Convention UN Environment/MAP, HELCOM, Black Sea Commission) [5], the Italian association *Legambiente*. This has led the environmental scientific community to promote new projects, following protocols for the management and sustainable use of coastal zones, such as ICZM (Integrated Coastal Zone Management) [2].

2. Research topics

The monitoring of coastal and marine environments is carried out jointly by the Computer Vision and Pattern Recognition Laboratory (CVPRL) "Alfredo Petrosino", the Computational Intelligence & Smart Systems Laboratory

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[1]International Panel on Climate Change - (www.ipcc.ch)

(CI&SS), the High-Performance Scientific Computing Laboratory (HPSC) and the Neptun-IA Interdisciplinary Laboratory of the University of Naples Parthenope. Artificial Intelligence (AI) techniques, in particular, Computational Intelligence (CI), Machine Learning (ML), Deep Learning (DL), and Computer Vision (CV) are applied to the field of interest for the detection of anthropogenic debris released in coastal and marine environments using aerial and underwater drones. These activities follow the numerous guidelines established by MedECC (Mediterranean Experts on Climate and Environmental Change), with the support of the European Community, and aim at protecting those marine and coastal ecosystems where the rate of pollution is increasing. The research involves the implementation of several tasks, such as the processing of aerial and submarine images; the development of object recognition techniques; the development of optimization strategies for garbage collection; the development of techniques for drone guidance; feature drift detection [6]; Virtual Reality (VR) reconstruction of real scenes captured by video cameras. The tools have a minimal impact on the environment and can be used in marine protected areas and marine archaeological parks. The activities are coordinated in the CVPRL "Alfredo Petrosino" and CI&SS labs, which are respectively the Parthenope node of the CINI Artificial and Intelligent Systems (AIIS) lab and the CINI BIG Data node, for the development and implementation of the AI algorithms. The HPSC lab is the CINI HPC node and develops the HPC architectures required for the AI algorithms. The Neptun-IA lab provides the necessary expertise for coastal monitoring issues and the synergy of activities between AI and the environmental domain.

3. Task descriptions

3.1. Beach *litter* recognition

Beach litter monitoring [7], [8], [9] programs play a key role in establishing effective management measures to preserve the ecological, scenic, and economic value of the coastal areas. In this study, an innovative analysis system is proposed for the automatic identification of beach debris on aerial-photogrammetric images acquired by unmanned aerial vehicles (UAV) at different elevations. A first version of the workflow (Fig. 1) is based on a Mask-RCNN model [7], here actually used for instance segmentation tasks (Fig. 1). Test cases were conducted along the Adriatic sector of the Apulia region (Italy), where the beaches have remarkable economic importance, attracting national and international tourists, and ecological values, hosting species of high ecological value and protected areas. The images were acquired at two coastal sites, Torre Guaceto, a marine protected

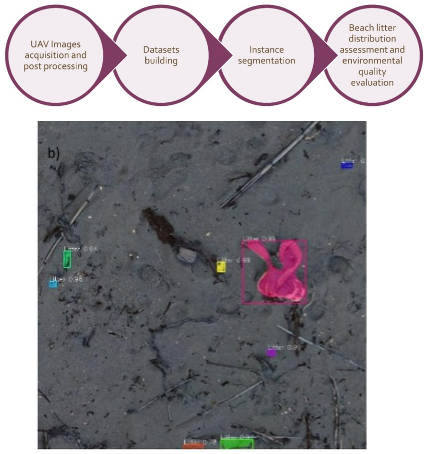

Figure 1: System workflow (top) and Litter recognition examples (bottom).

area of Apulia located on the Adriatic coast of Upper Salento, and Torre Canne, a marine site located a few tens of kilometers from Brindisi, which falls within the Regional Natural Park of the Dune Costiere, from Torre Canne to Torre San Leonardo. The results of the tests carried out in this study allowed for defining $10m$ as the desirable drone flight above ground. The proposed methodology represents a benchmark for the definition of a standardized procedure for the indirect evaluation and monitoring of the coastal environmental status. Besides allowing the investigation of large areas with limited human effort, the proposed system enables the evaluation of the beach litter spatial distribution and magnitude, providing useful information for the assessment of tailored beach quality indices. Additional comparisons in the realm of machine learning for beach litter monitoring systems have been conducted, juxtaposing the QGIS ML Toolkit against the methodology presented in this study. The QGIS ML Toolkit employs segmentation and classification processes independently, utilizing Meanshift and Support Vector Machine algorithms, respectively. The findings of [8] reaffirm the superior performance of Mask-RCNN when compared to traditional methods.

Since models for instance segmentation require many annotated images to obtain significant results, and the annotation process, although supported by software tools for labeling, is extremely time-consuming, a new approach based on *HyperGraph Convolutional Networks* is developed for a *Weakly-supervised semantic segmentation (HyperGCN-WSS)* [10]. Specifically, HyperGCN-WSS constructs spatial and k-Nearest Neighbor (k-NN) graphs from the images in the dataset to generate the hypergraphs. Then, it trains a convolutional network architecture with specialized hypergraphs (HyperGCN) using

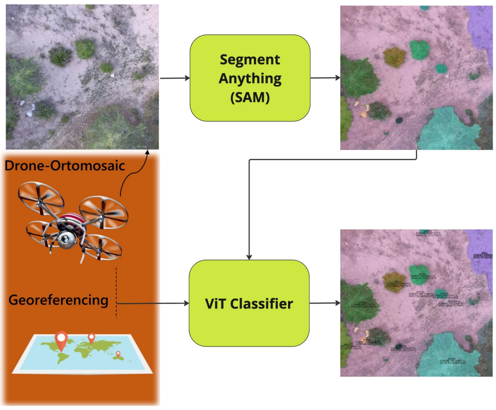

Figure 2: New beach litter recognition and geolocalization pipeline.

some *weak signal*. The outputs of the HyperGCN are called pseudo-labels, which are later used to train a fully convolutional network for semantic segmentation. The advantage of such a model is accurate semantic segmentation with small training data sets. Besides, a new version of this study has been proposed. The updated framework now incorporates both SAM (SegmentAnything Model) [11] and VIT (Vision Transformer) [12] algorithms to enhance its capabilities [9]. SAM is utilized for robust instance segmentation, ensuring accurate identification and delineation of individual objects within the coastal environment. Additionally, VIT is employed for classification tasks, allowing for the categorization of various coastal elements such as sand, vegetation, and sea. Furthermore, the geolocalization of each detected instance is refined to ensure precise mapping of environmental features globally. This integration of advanced algorithms significantly improves the framework's performance, enabling comprehensive analysis and monitoring of coastal areas with enhanced accuracy and efficiency (Fig. 2). Beach litter recognition is a collaboration with the Department of Earth and Geoenvironmental Sciences, University of Bari Aldo Moro, which provided the images for analysis, whereas HyperGCN-WSS is a collaboration with the *MIA Laboratory* of the University of La Rochelle, France.

Furthermore, the use of CI based methodologies (i.e., deep learning and multi-objective optimization through genetic algorithms) for predicting marine debris trajectories by UAV and for optimal path recovery for an autonomous vehicle was investigated [13]. For this purpose, realistic data generated by an oceanographic model (e.g. Lagrangian and particle drift models) on semi-submerged bottles were studied. The methodology allows obtaining the exact location of the marine debris over time and then developing a recovery strategy to optimize the time and distance of the automated catamaran that will be responsible for the recovery of the marine debris.

3.2. Underwater *litter* detection

This activity aims to study, develop and apply image processing (IP), DP and CI methods for the detection of underwater debris using drones. Recent research in the iMTG (Innovative Marine Technology for Geology & Archaeology), CI&SS and Neptun-IA laboratories has aimed at developing a system capable of detecting and recognizing seafloor objects using the ARGO drone. ARGO is a geophysical information-gathering drone equipped with several onboard cameras and a device (i.e. Raspberry PI) containing the object recognition module. The limited computational capacity of the hardware and the need for real-time response imply the design of a model that optimizes and reduces computational and memory requirements.

ArgonautAI [14], is a containerized distributed processing platform for autonomous surface vehicles. The ArgonautAI architecture uses a cluster of single-board computers with diverse and different characteristics (computing power, CUDA GPUs, FPGAs, GPIOs, PWMs, specialized I/O), orchestrated using Kubernetes and a customized programming interface. The proposed platform has been applied to AI-based marine debris detection using a hierarchical computer vision approach on heterogeneous onboard computing resources. In Fig. 3 the architecture of the platform. This platform has been designed to be used on the ARGO marine drone for future development.

Latest studies, as part of the DataX4Sea project, include upgrading the platform with a microservice management system called DataX[15], based on Kubernetes, to improve resource utilization in a real-time manner. To improve the detection of underwater litter, a study was conducted combining two techniques, one for color reconstruction (SeaThru) useful for submarine color correc-

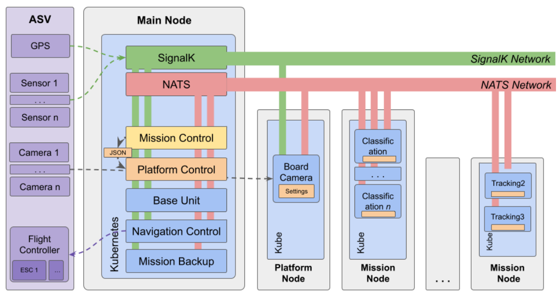

Figure 3: ArgonautAI Platform's Architecture

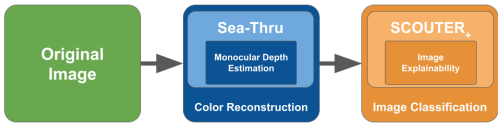

Figure 4: Pipeline for underwater marine litter detection - Image is pre-processed using Sea-Thru, then classification is performed using SCOUTER

tion using monocular depth estimation, in conjunction with the SCOUTER slot-attention based classification model for explainable learning (XAI) [16]. The entire pipeline (Fig.4) for floating and underwater marine litter classification, was used as part of a particular marine data crowdsourcing platform, Citizien Science for the Sea with Information Technologies (C4Sea-IT) for gathering marine data from leisure boat instruments[17]. For the detection of environmental objects a system based on a Deep Neural Networks [18] has been designed for the marine ARGO drone. The proposed architecture is based on the Single Shot MultiBox Detector model, a particular class of CNNs that combines localization and classification using a single deep neural network, thus limiting the explosion of the computational complexity of the network.

The expected results of the research are the production of a tool capable of innovating and automating the process of detection and removal of solid waste in marine environments employing "explainable" decision-making systems based on approximate reasoning [19, 20] and data integration methodologies [21]. In Fig. 5 results of combining the color reconstruction technique for underwater images (Sea-Thru) object classification based on the SCOUTER model. The degree of innovation of the proposed research is high, as there is currently no established scientific research in this direction involving the development and use of drones capable of efficiently exploring shallow-water marine coastal environments. Moreover, the marine drone that will be used in the research (ARGO) is an open project prototype, optimized to carry out non-invasive, high-resolution indirect surveys in very shallow water areas, with almost no environmental impact, allowing it to be also used in marine protected areas and underwater archaeological parks.

Due to the lack of large datasets for underwater object recognition tasks, a synthetic dataset of underwater scenes with optical flow labels [22] has been created to demonstrate the benefits of training a specific deep neural model for optical flow estimation in the considered environment. Experimental comparisons between a general-purpose deep neural model and the same model specifically trained with the newly proposed dataset have confirmed an increase in the accuracy of the final estimation.

3.3. Mussels farm quality assessment and prediction

The quality of coastal marine waters is representative of the environmental sustainability of the human activities in the area. However, the urban settlements, the industrial plants, the agriculture, and the animal husbandry produce effects potentially compromising the aquatic ecosystems, damaging the landscape and the social/economic sectors. Monitoring the impact of the pollutants on the sea is crucial for coastal human activities, such as aquaculture. In addition, fish and mussel farms are critically sensitive to seawater quality and thus require continuous monitoring to enforce food security and prevent any possible disease affecting human health, both of chemical and biological origin [23]. However, leveraging a continuous microbiological laboratory analysis is unfeasible for costs and practical reasons. A convenient solution is a computational approach to mitigate the coast connected to the in-situ monitoring and predict the water quality evolution concerning the coastal hydrodynamics and the known pollution source activities [24].

This study aims to develop a novel methodology to pre-

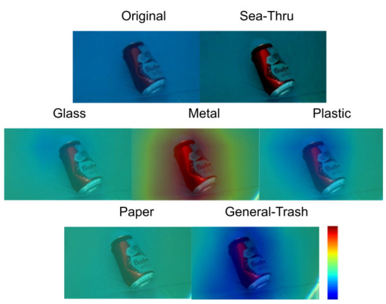

Figure 5: Heatmap of Scouter+ XAI methodology on metal marine litter preprocessed by Sea-Thru

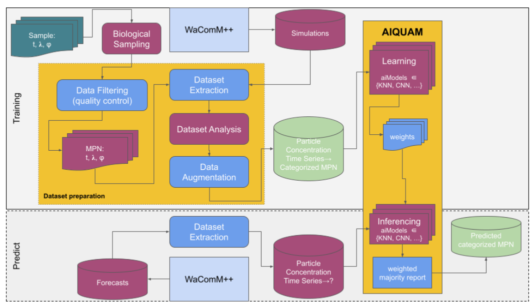

Figure 6: The AIQUAM architecture and data flow for both training ad predict stages.

dict water quality as categorized indexes leveraging an integrated approach between computational components and artificial intelligence techniques. To face this issue, AIQUAM (Artificial Intelligence-based water QUAlity Model), a decision-making tool based on coupling HPC numerical models with three artificial intelligence (AI) models [25, 26], has been developed (Fig. 6). AIQUAM implements an AI model for seawater quality predictions. The model performs time series classification leveraging various and different algorithms and then performs a weighted majority report for predicting the best result. AIQUAM aims to predict the contaminant levels in mussels to support the local authorities in monitoring aquaculture.

4. Projects

- SMARTWIN (Digital Twin and Fintech Services for Sustainable Supply Chain), progetto MISE.
- PAS (PAESAGGI ARCHEOLOGICI SOMMERSI DELLA CAMPANIA), progetto MISE.
- Computational Intelligence Methods for Digital Health, GNCS.
- HPC-Based navigation system for Marine Litter hunting, FF4EUROHPC .
- Tecniche di Machine Learning e di Soft Computing per l'elaborazione di dati MultiVARIATI (SOFTMULAN), Dipartimento di Scienze e Tecnologie, Università degli Studi di Napoli Parthenope.
- Progetto Parco Archeologico Urbano di Napoli (PAUN), PON 03PE 00164, Rete Intelligente dei Parchi Archeologici (RIPA - PAUN).
- Erasmus+ "Framework for Gamified Programming Education" (FGPE).
- Euro-HPC H2020 "Adaptive multi-tier intelligent data manager for Exascale" (ADMIRE).
- DataX4Sea project (DX4S) (CUP I63C22000270005) funded by the NEC Laboratories of America.
- SE4I (Smart Energy Efficiency & Environment for Industry), PON, area di specializzazione: Fabbrica Intelligente.
- Convenzione con Unlimited Technology srl nell'ambito del progetto H2020 "Piattaforma Logistica Integrata 4.0 - P.L.I 4.0".
- Convenzione di ricerca DIST-Università di Napoli Parthenope e Dipartimento di Scienze della Terra e Geoambientali dell'Università degli Studi di Bari "Aldo Moro", "Monitoraggio dell'Ambiente Costiero e della Marine & Beach Litter Attraverso Metodi di Indagine Diretti, Indiretti e di Machine Learning".

5. Conclusions

This paper proposes an overview of the research activities carried out in the various laboratories of the University of Naples Parthenope that attempt, with strong and close cooperation and collaboration, to effectively address issues concerning the preservation of marine and coastal environments. As shown, they try to approach the various problems using low environmental impact approaches, which therefore, neither damage nor modify the pre-existing ecosystem. The use of Artificial Intelligence is a key factor in being able to enable such results, using state-of-the-art techniques and developing new ones. This allows the results to be optimized to be reliable in a complex context such as maritime. In addition, the possibility of being able to use these systems efficiently is also possible thanks to the optimization obtained from the high-performance architectures modeled during the various research projects that are reported. The synergy between the laboratories and the other partners involved, allows, therefore, to attempt to solve the problems that man himself has created, making it effective and of great importance to continue to invest energies in the implementation of such projects.

References

[1] M. D. V. L. Bonora, D. Carboni (Ed.), Eighth International Symposium on Monitoring of Mediterranean Coastal Areas. Problems and Measurement Techniques, Proceeding and Report, Firenze University Press, 2020. doi:10.36253/978-88-5518-147-1.

[2] MATTM-Regioni, Linee Guida per la Difesa della Costa dai fenomeni di Erosione e dagli effetti dei Cambiamenti climatici, Technical Report, Documento elaborato dal Tavolo Nazionale sull'Erosione Costiera MATTM-Regioni con il coordinamento tecnico di ISPRA, 2018.

[3] M. Davidson, Forecasting coastal evolution on timescales of days to decades, Coastal Engineering 168 (2021).

[4] W. Cramer, J. Guiot, M. Fader, J. Garrabou, J.-P. Gattuso, A. Iglesias, M. lange, P. Lionello, M. Llasat, S. Paz, et al, Climate change and interconnected risks to sustainable development in the mediterranean, Nature Climate Change 8 (2018) 972–980.

[5] A. Addamo, P. Laroche, G. Hanke, Top marine beach litter items in europe, 2017. doi:10.2760/496717.

[6] A. Ferone, A. Maratea, Adaptive quick reduct for feature drift detection, Algorithms 14 (2021).

[7] V. Scarrica, P. Aucelli, C. Cagnazzo, A. Casolaro, P. Fiore, M. L. Salandra, A. Rizzo, G. Scardino, G. Scicchitano, A. Staiano, A novel beach litter analysis

system based on uav images and convolutional neural networks, Ecological Informatics 72 (2022).
[8] A. Sozio, V. M. Scarrica, P. P. Aucelli, G. Scicchitano, A. Staiano, A. Rizzo, Comparing meanshift/svm and mask-rcnn algorithms for beach litter detection on uavs images, in: 2023 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea), 2023, pp. 483–487.
[9] A. Sozio, A. Rizzo, V. M. Scarrica, P. P. C. Aucelli, G. Anfuso, G. Barracane, L. A. Dimuccio, R. Ferreira, M. La Salandra, A. Staiano, M. P. Tarantino, G. Scicchitano, An innovative sam-vit based tool for the automatic detection of litter items on sandy beaches, in: EGU General Assembly 2024, 2024.
[10] J. H. Giraldo, V. Scarrica, A. Staiano, F. Camastra, T. Bouwmans, Hypergraph convolutional networks for weakly-supervised semantic segmentation, in: 2022 IEEE International Conference on Image Processing (ICIP), 2022, pp. 16–20.
[11] A. Kirillov, E. Mintun, N. Ravi, H. Mao, C. Rolland, L. Gustafson, T. Xiao, S. Whitehead, A. C. Berg, W.-Y. Lo, P. Dollar, R. Girshick, Segment anything, in: Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), 2023, pp. 4015–4026.
[12] A. Kolesnikov, et al., An image is worth 16x16 words: Transformers for image recognition at scale, 2021.
[13] V. Bevilacqua, A. et al. Di Marino, A. Ciaramella, A. A. Biancardi, G. Budillon, P. de Ruggiero, E. Della Volpe, L. Gifuni, D. Mascolo, S. Pierini, E. Zambianchi, Computational Intelligence for Marine Litter Recovery, Springer Nature Singapore, 2023, pp. 137–145.
[14] G. Mellone, C. G. De Vita, D. D. Sánchez-Gallegos, D. Di Luccio, G. Mattei, F. Peluso, P. P. C. Aucelli, A. Ciaramella, R. Montella, A containerized distributed processing platform for autonomous surface vehicles: Preliminary results for marine litter detection, in: 2023 31st Euromicro International Conference on Parallel, Distributed and Network-Based Processing (PDP), IEEE, 2023, pp. 144–148.
[15] G. Coviello, K. Rao, M. Sankaradas, S. Chakradhar, Datax: A system for data exchange and transformation of streams, in: International Symposium on Intelligent and Distributed Computing, Springer, 2021, pp. 319–329.
[16] A. Maratea, A. Ferone, Deep neural networks and explainable machine learning, in: R. Fullér, S. Giove, F. Masulli (Eds.), Fuzzy Logic and Applications, Springer International Publishing, Cham, 2019, pp. 253–256.
[17] C. G. De Vita, G. Mellone, D. D. Sanchez-Gallegos, G. Coviello, D. Romano, M. Lapegna, A. Ciaramella, Citizen science for the sea with information technologies: an open platform for gathering marine data and marine litter detection from leisure boat instruments, in: 2023 IEEE 19th International Conference on e-Science (e-Science), IEEE, 2023, pp. 1–9.
[18] A. Ciaramella, F. Perrotta, G. Pappone, P. Aucelli, P. F., G. Mattei, Environment object detection for marine argo drone by deep learning 1266 (2021).
[19] E. Di-Nardo, A. Ciaramella, Advanced fuzzy relational neural network, in: Proccedings of The 13th International Workshop on Fuzzy Logic and Applications (WILF 2021), CEUR Workshop Proceedings, 2021.
[20] F. Camastra, et al., A fuzzy decision system for genetically modified plant environmental risk assessment using mamdani inference, Expert Systems with Applications 42 (2015) 1710–1716.
[21] A. Ciaramella, D. Nardone, A. Staiano, Data integration by fuzzy similarity-based hierarchical clustering, BMC Bioinformatics 21 (2020).
[22] A. Ferone, M. Lazzaro, V. M. Scarrica, A. Ciaramella, A. Staiano, A synthetic dataset for learning optical flow in underwater environment, in: Applications of Artificial Intelligence and Neural Systems to Data Science, Smart Innovation, Systems and Technologies, in press.
[23] A. Galletti, R. Montella, L. Marcellino, A. Riccio, D. Di Luccio, A. Brizius, I. Foster, Numerical and implementation issues in food quality modeling for human diseases prevention, in: Special Session on Smart Medical Devices-From Lab to Clinical Practice, volume 6, SCITEPRESS, 2017, pp. 526–534.
[24] R. Montella, D. Di Luccio, C. G. De Vita, G. Mellone, M. Lapegna, G. Ortega, L. Marcellino, E. Zambianchi, G. Giunta, A highly scalable high-performance lagrangian transport and diffusion model for marine pollutants assessment, in: 2023 31st Euromicro International Conference on Parallel, Distributed and Network-Based Processing (PDP), IEEE, 2023, pp. 17–26.
[25] C. G. De Vita, G. Mellone, D. Di Luccio, S. Kosta, A. Ciaramella, R. Montella, Aiquam: Artificial intelligence-based water quality model, in: 2022 IEEE 18th International Conference on e-Science (e-Science), IEEE, 2022, pp. 401–402.
[26] C. G. De Vita, G. Mellone, F. Barchiesi, D. Di Luccio, A. Ciaramella, R. Montella, Artificial intelligence for mussels farm quality assessment and prediction, in: 2022 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea), IEEE, 2022, pp. 33–38.