AI-based Monitoring of Coastal and Marine Environments

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Abstract

Human and natural processes continuously threaten coastal and marine ecosystems. Human being has, since the last century, undermined the coastal equilibrium, accentuating or sometimes triggering irreversible erosive phenomena and causing salt wedge intrusion in areas where agricultural production represents a relevant inducement for the local economy. Also critical is the overexploitation of sandy shores, with the consequent alteration of the beach environment, and sometimes 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 their marine living organisms. Aiming at addressing the challenges from the above context, the CVPR and CI&SS Labs, both affiliated with the interdisciplinary Lab Neptun-IA of the Department of Science and Technology at the University of Napoli Parthenope, started working on several tasks related to beach and undersea litter detection and recognition through Artificial Intelligence and Computer Vison-based techniques.

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 the human being has, since the last century, undermined the coastal equilibrium, accentuating or sometimes triggering irreversible erosive phenomena and causing salt wedge intrusion in areas where agricultural production represents a relevant inducement for 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 (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, Machine

Ital-IA 2023: 3rd National Conference on Artificial Intelligence, organized by CINI, May 29–31, 2023, Pisa, Italy
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[1]International Panel on Climate Change - (www.ipcc.ch)

Learning (ML), Deep Learning (DL) Computational Intelligence (CI), 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; 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 underwater archaeological parks. The activities are coordinated in the CVPRL "Alfredo Petrosino" 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, CINI HPC node, 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 [6] 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. The workflow (Fig. 1) is based on a Mask-RCNN model, 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 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. 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 *semantic segmentation Weakly-supervised (HyperGCN-WSS)* [7]. Specifically, HyperGCN-WSS constructs spatial and k-Nearest Neighbor (k-NN) graphs from the images in the dataset to generate the hypergraphs. It then trains a convolutional network architecture with specialized hypergraphs (HyperGCN) using 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.

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 [8]. 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 (Fig. 2). ARGO is a geophysical information-gathering drone equipped with several onboard cameras and a device (i.e.

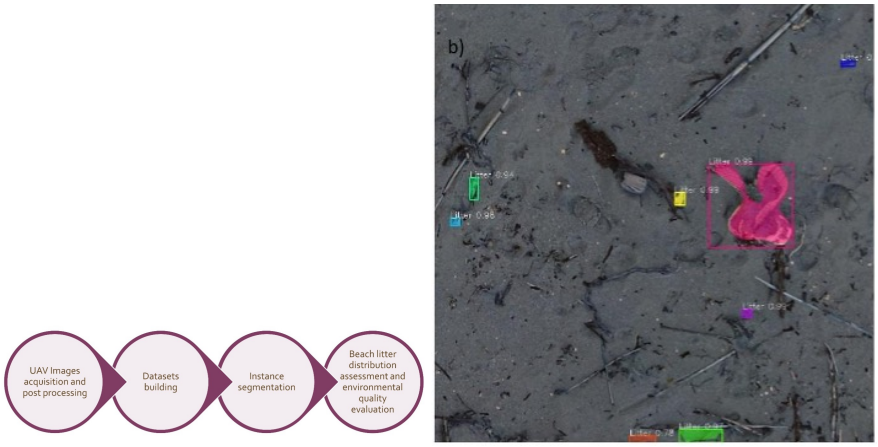


Figure 1: System workflow (left) and Litter recognition examples (right).

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 [9], 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 solution introduces two different types of containers, the former managing the vehicle's instruments (e.g., position, attitude, environment, depth), data storage, ship-to-shore communication, etc., and the latter hosting mission-specific software components. The proposed platform has been applied to AI-based marine debris detection using a hierarchical computer vision approach on heterogeneous onboard computing resources.

For the detection of environmental objects a system based on a Deep Neural Networks [10] 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 [11, 12] and data integration methodologies [13]. 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 [14] 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. Development of digital twins of aerial and maritime drones

The goal of this activity is to create digital models (digital twins) of aerial and marine drones that can be used to test and understand how they behave under varying weather conditions, environmental complexity, onboard sensors, and navigation algorithms using virtual space and simulation. A first prototype digital twin of the ARGO maritime drone has already been built (Fig. 2) using the *aws* robotics tool (https://aws.amazon.com/it/robomaker/). The digital duplicate created is a three-dimensional representation of the drone that contains all the information of the physical drone, including its mechanics, geome-

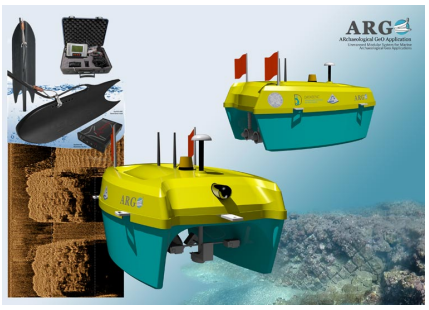
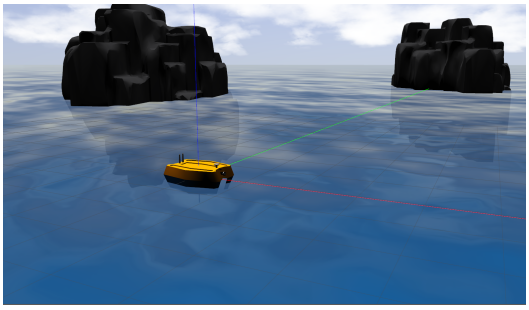
a)  b) 

Figure 2: a) The real ARGO drone and b) its digital twin.

try, sensors (Gps, side scan sonar, echosounder, camera, p900 forward scan sonar), actuators, and related data and software. The goal is to take advantage of this enabling technology both for experimental activities such as incremental testing of adding sensors to optimize navigation in the unstructured and open environment and for data collection; and for activities to predict possible anomalies, failures, and identification of unanticipated risks in the design phase of the physical prototype, this at the cost of large savings in time and cost for direct physical model creation and a risk reduction.

4. Projects

- 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).
- 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".

Acknowledgments

The work was supported by the fundamental contributions of the following people:

- *Ciro Giuseppe De Vita* and *Gennaro Mellone*, students of the PhD Course in "Environmental Phenomena and Risks" cycle XXXVII, Università di Napoli Parthenope, Italy;
- *Vincenzo Mariano Scarrica*, student of the Italian National PhD Course in Artificial Intelligence - Agrifood and Environment, cycle XXXVII, Università di Napoli Federico II and Università di Napoli Parthenope, Italy;
- *Angelo Casolaro*, student of the Italian National PhD Course in Artificial Intelligence - Agrifood and Environment, cycle XXXVIII, Università di Napoli Federico II and Università di Napoli Parthenope, Italy;

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