AI-Based Marine Biofouling Classification and Forecasting for Offshore Renewable Energy Infrastructure

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1.1 Background and Motivation

Marine biofouling is the accumulation of organisms on submerged structures, affecting the operation, maintenance, and reliability of offshore renewable energy systems. Marine growth varies with site and environmental conditions (Picken, 1995) and begins almost immediately after installation (Teng and Nath, Proc. OTC, 1989). In offshore wind, waves, and current energy devices, biofouling increases hydrodynamic loading (Emamdoost et al., Proc. OTC, 2026; Marty et al., Mar. Sci. Eng., 2021), reduces fatigue life (Rashid et al., Eng. Appl. Artif. Intell, 2024) and increases inspection and maintenance requirements. Recent studies have applied deep convolutional neural networks (CNNs) for biofouling classification (Signor et al., Ocean Eng., 2023; Chin et al., Complexity, 2017) and machine learning for biofilm growth prediction (Tanudjaja et al., npj Clean Water, 2025; Rashid et al., Expert Syst. Appl. 2025; Lang et al., Transp. Res. Part D, 2026). However, integrated AI frameworks combining image-based biofouling classification with probabilistic thickness prediction remain limited. This study presents an integrated AI framework combining deep-learning image classification with Bayesian probabilistic thickness prediction to support offshore inspection and engineering decision-making.

1.2 Approach

An integrated AI framework combined a ResNet50 convolutional neural network (CNN) for marine biofouling classification with Bayesian Gaussian Process (GP) regression for probabilistic thickness prediction. A dataset of 1,170 labeled underwater images representing four fouling classes (mussels, barnacles, worms, and soft fouling) was used to train CNN. The predicted fouling class was then used by the Bayesian (GP) model to estimate biofouling thickness from an underwater inspection database of two North Sea offshore structures. The integrated workflow supports offshore inspection and maintenance by providing probabilistic estimates of biofouling thickness.

1.3 Results

The initial results of the proposed framework showed strong classification performance, with an overall accuracy of approximately 85%, especially for mussel and soft fouling classes. The Bayesian GP model also demonstrated promising prediction performance on unseen data, achieving a cross-validated R^2 of 0.68. The next stage of this work requires field studies, experimental measurements, and large-scale image and sensor datasets to expand the dataset and enhance Bayesian prediction of biofouling thickness and severity, supporting inspection planning, maintenance, and cost reduction for marine renewable energy infrastructure.



(a) (b) (c)

Figure 1. (a) ResNet50 confusion matrix, (b) True prediction of the mussel class, and (c) True prediction of the soft fouling class.