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Optimization Based Undersampling for Imbalanced Classification using Whale Algorithms and Random Forest

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Abstract

Class imbalance remains a persistent challenge in machine learning, often causing classifiers to be biased toward majority classes. To mitigate this, this study presents a modified undersampling framework based on the Whale Optimization Algorithm (WOA) and Binary WOA (BWOA) combined with K-nearest neighbor (KNN) evaluation. Two distinct strategies are introduced: WBWOA-1NN, which utilizes a fixed neighborhood size ($K = 1$), and WBWOA-KNN, which employs an adaptive mechanism to optimize K. The approach is evaluated on ten benchmark datasets with imbalance ratios ranging from 1.82 to 42.01. By fully preserving minority samples while optimizing majority subsets for Random Forest classification, the method ensures data integrity. Experimental results indicate that WBWOA-KNN achieves robust performance, particularly in Sensitivity (Recall), G-mean, Area Under the Receiver Operating Characteristic Curve (AUROC), and MCC. The findings demonstrate that the proposed framework consistently outperforms traditional methods like Random Undersampling, Cluster Centroids, and Near-Miss, offering a superior solution for handling highly imbalanced classification tasks.

Keywords: Imbalanced Data; Undersampling; Whale Optimization Algorithm; Binary Whale Optimization Algorithm

Introduction

Class imbalance severely biases standard classification algorithms, resulting in the poor detection of rare, critical events (He & Garcia, 2009). While naive undersampling mitigates this, it often discards informative majority instances, which degrades performance. To address this, we propose an optimization-driven undersampling framework using the Whale Optimization Algorithm (WOA) and its binary variant (BWOA) (Mirjalili & Lewis, 2016). By formulating majority-class selection as an optimization problem evaluated via K-nearest neighbor (KNN), the framework preserves discriminative majority instances and fully retains all minority samples, improving minority detection without modifying the underlying classifier. We introduce two KNN-evaluated variants, validated on benchmark datasets. WOA is utilized due to its strong balance between global exploration and local exploitation, making it highly effective for searching high-dimensional, combinatorial spaces like subset selection (Nadimi-Shahraki et al., 2023). Random Forest serves as the base classifier because its robustness to noise and high-dimensional data provides a stable backbone, effectively isolating and demonstrating the impact of our proposed undersampling strategy (Chen, Liaw & Breiman, 2004).

Methodology / Proposed Approach

Our hybrid framework integrates WOA/BWOA with KNN to select representative majority subsets. Two variants are proposed: WBWOA-1NN (fixed K=1) and WBWOA-KNN (WOA adaptively

optimizes K ∈ [1, 30] while BWOA simultaneously selects instances). Validation employs ten datasets (KEEL, 2024; imbalanced-learn) with imbalance ratios of 1.82–42.01 (*glass1, iris0, glass-0-1-2-3_vs_4-5-6, ecoli2, ecoli, abalone, Libras Movement, solar_flare_m0, yeast_m2, Mammography*). Data is partitioned into 80% training (where undersampling is exclusively applied) and 20% testing. An RF classifier, tuned via 10-fold cross-validation, is evaluated on the test set using accuracy, sensitivity, precision, G-mean, F-measure, AUROC, MCC, and Cohen's kappa.

Experimental Results & Discussion

Baseline RF on raw data showed high accuracy (0.9365) but poor sensitivity (0.5563). Conversely, WBWOA-KNN achieved the highest sensitivity (0.9399) and G-mean (0.8794), while outperforming conventional methods (Random Undersampling, Cluster Centroids, Near-Miss) in MCC (0.5705) and Kappa (0.5123) with a competitive AUROC (0.9212). The adaptive WBWOA-KNN proved more robust than the fixed WBWOA-1NN, successfully mitigating majority bias and providing a reliable imbalanced classification solution.

Conclusion

The proposed frameworks successfully enhance minority detection by constructing representative majority subsets. WBWOA-KNN yields superior balance over traditional methods. However, metaheuristic optimization introduces computational overhead and parameter sensitivity. Future work will focus on optimizing efficiency, multi-class extensions, and deep learning integration for large-scale applications.

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