A Hybrid Machine Learning Approach for Real-Time Beach Safety

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Abstract - Ensuring beach safety is vital for safeguarding public health and enabling recreational activities. This study introduces a hybrid framework that combines dynamic threshold-based risk filtering, unsupervised clustering, and ensemble classification to assess and categorize beaches based on safety levels. First, real-time environmental and oceanographic measurements, such as wave height, water temperature, turbidity, and other meteorological conditions, are evaluated against adaptive thresholds: data points failing any criterion are immediately flagged as unsafe. Measurements that satisfy all thresholds are then processed through an unsupervised clustering algorithm to uncover distinct safety patterns. Finally, an ensemble of classification models is applied to clustered data to enhance predictive robustness and accuracy. When unsafe conditions are identified, the system alerts end users immediately.

Key Words: Beach Safety, Threshold Filtering, Clustering Algorithm, Classification, Real-time Prediction, API Integration

1.INTRODUCTION

Recreational beaches attract millions globally, yet unpredictable ocean dynamics and environmental factors pose risks ranging from rip currents to poor water quality. Traditional safety assessments often rely on manual inspections or fixed-point measurements, which may lack timeliness or granularity. To address these challenges, automated systems have emerged that integrate real-time APIs with algorithmic analysis. Our work introduces a three-stage decision pipeline: a threshold-based gatekeeper for immediate safety alerts, an unsupervised clustering stage to reveal finer-grained patterns in safe-beach conditions, and an ensemble of classifiers used on clustered data to enhance prediction accuracy. By uniting these methodologies, we aim to improve both real-time responsiveness and longer-term strategic insights.

2. System Architecture and Design

The proposed system comprises three core layers:
1) data acquisition, 2) processing and decision logic, and
3) visualization and alerting.

A. Core Components:
API Integration Layer: Fetches real-time environmental and oceanographic data from trusted external sources (e.g., INCOIS APIs).
Central Server: Processes incoming API data, applies threshold logic, and manages clustering models.
Database: A time-series database stores historical measurements for model recalibration and pattern discovery.
Dashboard Interface: A responsive web application provides real-time visualization and system control.

B. Technical Stack:
Data Source: INCOIS API or other meteorological and oceanographic web services.
Programming: Python for data processing
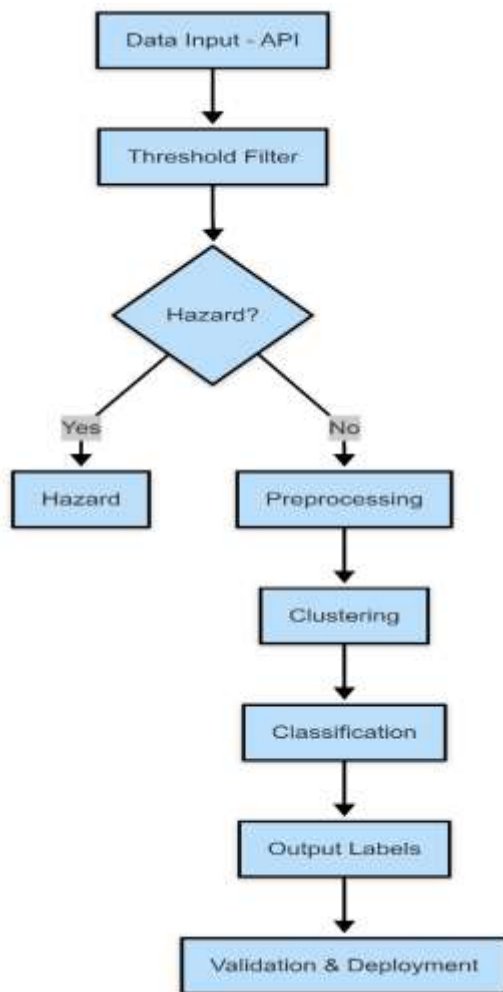Data Processing: Pandas, NumPy, Matplotlib
Clustering: scikit-learn (K-Means)
Classification: scikit-learn (Random Forest, Gradient Boosting, MLP Classifier)
Visualization: Android APK using Android Studio
Communication: RESTful APIs to put and fetch data.
Deployment: Render to host the Flask WebApp and Android Studio for Android APK.

Fig -1: Working of Beach Safety System

In the acquisition layer, APIs are periodically polled to collect parameters including wave height, turbidity, water temperature, and meteorological data. Data are processed in real-time using distributed computing principles for scalability and fault tolerance. Within the processing layer, an adaptive threshold module evaluates each data record against predefined safety bounds that adjust based on historical trends and seasonal variations. Records flagged as unsafe trigger immediate alerts. while safe records proceed to the clustering engine. The clustering engine leverages a K-Means algorithm to automatically discover groupings of safe conditions, allowing detection of anomalous clusters or emerging trends. After clustering, a classification module further labels each instance using an ensemble of classifiers. Finally, the visualization layer presents the safety status.

3. METHODOLOGY

The proposed system uses a hybrid approach combining rule-based thresholding, clustering, and machine learning classification to assess beach safety. The methodology involves the following key steps:

1.Data Preprocessing: Environmental data (temperature, current speed, pH, turbidity, tide length,etc) is cleaned and normalized. The target variable Safety, is encoded for binary classification.
2.Thresholding:Initial filtering is applied using predefined thresholds. If any parameter falls outside safe limits, the system immediately flags the condition as Unsafe.
3.Clustering: If the input passes the threshold check, K-Means clustering groups the data to identify patterns and categorize similar environmental conditions.
4.Classification: An Ensemble of Classifiers(Random Forest Classifier,Gradient Boosting,MLP Classifier) is trained to predict the safety label using the preprocessed features.
5.Deployment: The model is deployed using a RESTful API. Users interact with the system via an Android-based mobile application to input data and receive real-time predictions and alerts.

4. CONCLUSIONS

We developed a three-stage hybrid framework that leverages real-time API data to enhance coastal safety monitoring.
Threshold Filtering swiftly flags extreme hazards in incoming measurements.
K-Means Clustering then separates the remaining data into two natural groupings:safe versus unsafe,achieving an 86.4 % clustering accuracy.
Ensemble Classification applied to the filtered and clustered dataset yields a robust 91 % classification accuracy.
These results demonstrate the system's ability to both rapidly detect dangerous conditions and accurately differentiate among safe scenarios. Its modular design and reliance on live API feeds enable seamless integration with existing coastal-management platforms. Future work will focus on adaptive threshold tuning via reinforcement learning, the inclusion of crowd-sourced feedback to enhance cluster interpretability, and expansion to additional environmental and biological indicators for even more comprehensive beach-safety decision support.

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