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IMPROVING SPAM DETECTION ACCURACY WITH RANDOM FOREST AND TEXT VECTORIZATION

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ABSTRACT

With the exponential growth of digital communication, email and messaging platforms have become a major vector for spam. Effective spam detection is essential to enhance user experience, reduce resource consumption, and ensure information security. This paper presents a machine learning-based approach for spam detection using the Random Forest classifier. The model was trained and tested on a benchmark dataset, achieving an accuracy of 87.77%. Random Forest, being an ensemble learning technique, aggregates the predictions from multiple decision trees to improve classification performance and reduce overfitting. The proposed system demonstrates reliable classification of spam and ham messages, showing that Random Forest can serve as a robust baseline method for text-based spam detection. Further analysis reveals that the model balances precision and recall effectively, making it suitable for real-time deployment in email filtering systems.

1. INTRODUCTION

In recent years, the widespread adoption of digital communication has led to an increase in unsolicited and often malicious messages, commonly referred to as spam. Spam messages not only clutter user inboxes but can also serve as vehicles for phishing, malware distribution, and fraudulent schemes. As a result, accurate and efficient spam detection mechanisms have become a critical component of secure and user-friendly communication systems.Traditional spam filters relied heavily on rule-based and keyword-matching approaches, which often struggled to adapt to the evolving nature of spam. With the advent of machine learning, data-driven approaches have shown considerable promise in identifying patterns and anomalies in large volumes of textual data. Among various machine learning techniques, ensemble methods such as Random Forest classifiers have gained attention due to their ability to handle high-dimensional data and provide robust performance.This study explores the use of the Random Forest classifier for spam detection, leveraging its ensemble structure to combine multiple decision trees for more accurate predictions. The model was trained on a standard spam dataset and achieved a classification accuracy of 87.77%, indicating its effectiveness in distinguishing between spam and legitimate messages. This paper discusses the preprocessing steps, model architecture, evaluation metrics, and implications for deploying such models in real-world applications.

2. LITERATURE REVIEW

Spam detection has been an active area of research in the fields of information retrieval, natural language processing, and machine learning. Various techniques have been proposed over the years to effectively classify messages as spam or ham (non-spam), ranging from rule-based systems to modern statistical and machine learning models.Early spam filters relied heavily on **rule-based approaches** and **blacklist techniques**, which matched keywords or known spammer addresses. While simple to implement, these methods lacked adaptability and were easily bypassed by slightly altering the spam content [1].The introduction of **Naïve Bayes classifiers** marked one of the earliest applications of machine learning in spam detection. Its probabilistic nature and simplicity made it a popular choice, but it suffered from assumptions of feature independence, which limited its accuracy in more complex scenarios [2]. Subsequently, models like **Support Vector Machines (SVM)** were adopted due to their ability to handle high-dimensional data and perform well with sparse text features [3]. However, SVMs are computationally intensive and sensitive to parameter tuning. Recent research has also explored **deep learning** approaches, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), which can automatically extract hierarchical features from text. Although these methods often outperform traditional models in terms of accuracy, they require large datasets, high computational power, and are less interpretable [4].In contrast, **ensemble methods** like **Random Forests** and **Gradient Boosting** have shown to be effective in achieving a balance between accuracy, robustness, and interpretability. Random Forest, in particular, has demonstrated high performance in classification tasks by constructing a multitude of decision trees and aggregating their results to minimize overfitting and variance [5]. Studies by García et al. [6] and Almeida et al. [7] have shown that Random Forests outperform many single classifiers in spam detection tasks due to their ability to handle noisy and imbalanced data effectively.Despite these advancements, spam detection remains a challenging problem due to the evolving tactics of spammers and the linguistic diversity of spam messages. This study builds

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upon the foundation laid by previous research by implementing a Random Forest classifier and evaluating its performance on a benchmark spam dataset, aiming to strike a balance between accuracy, efficiency, and practical deployment feasibility. Ganga et al. [8] performed a comparative analysis between Logistic Regression and Random Forest for classifying electrical faults, emphasizing Random Forest's superior performance in terms of accuracy and interpretability. Their findings support the viability of Random Forest for classification tasks involving complex feature spaces, which is directly applicable to spam detection where text data often exhibits high dimensionality and redundancy. Pennam and Potula [9] demonstrated the potential of supervised learning in predictive modeling by developing a ride fare estimation system. Although the domain differs, their use of historical data and regression-based learning illustrates the value of data-driven techniques in solving real-world prediction problems. Their methodology highlights the importance of feature extraction and model selection—both of which are crucial in enhancing the accuracy of spam detection systems. Expanding beyond classification and prediction, Pennam [10] proposed a security architecture for healthcare systems using cloud computing. While primarily focused on system-level security, the paper reinforces the broader theme of using intelligent architectures—often underpinned by machine learning—for reliable and secure decision-making. The emphasis on privacy and reliability aligns with key concerns in spam detection, such as false positives and the impact of spam on user trust.

3. METHODOLOGY

This section outlines the systematic approach adopted for spam detection using the Random Forest classifier. The methodology comprises several stages: data collection, preprocessing, feature extraction, model training, evaluation, and optimization as shown in figure 1.

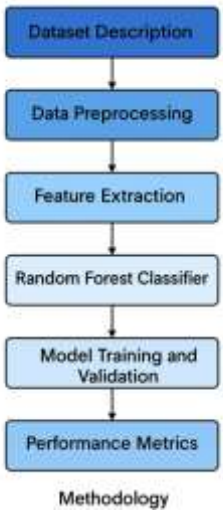


Figure.1 Flowchart

3.1 Dataset Description

The dataset used for this study is a benchmark SMS spam dataset, which contains a total of **5,572 labeled messages**, categorized into two classes: **'spam'** and **'ham'** (non-spam). Each entry consists of a message and its corresponding label. The dataset is imbalanced, with a larger number of ham messages than spam, which was accounted for during evaluation.

Spam messages: 747
Ham messages: 4,825
Total: 5,572

This dataset is publicly available and widely used in spam classification research, making it suitable for comparative evaluation.

3.2 Data Preprocessing

Text data is inherently noisy and unstructured. To improve model performance, the following preprocessing steps were applied:

1. **Lowercasing:** All text was converted to lowercase to ensure uniformity (e.g., "Free" and "free" are treated the same).
2. **Punctuation Removal:** All punctuation marks and special characters were removed.
3. **Tokenization:** Messages were split into individual words (tokens).
4. **Stop Words Removal:** Common English stop words such as "the", "is", and "in" were removed using the NLTK stopword list.
5. **Stemming/Lemmatization:** Words were reduced to their base form using the Porter Stemmer to handle variations (e.g., "running" → "run").
6. **Noise Removal:** URLs, numbers, and irrelevant whitespace were removed.

3.3 Feature Extraction

After cleaning, the text was transformed into numerical features using the **TF-IDF (Term Frequency-Inverse Document Frequency)** vectorizer, which captures the importance of words in relation to the entire corpus.

- **Term Frequency (TF):** Measures how frequently a term occurs in a message.
- **Inverse Document Frequency (IDF):** Measures how unique or rare a term is across all messages.

This results in a high-dimensional sparse matrix, where each message is represented by a vector of weighted term values.

3.4 Model Selection: Random Forest Classifier

Random Forest is an ensemble learning method that operates by constructing multiple decision trees during training and outputs the class that is the mode of the classes (classification) of the individual trees. Its advantages include:

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- **Robustness to overfitting**
- **Capability to handle high-dimensional data**
- **Interpretability through feature importance scores**

3.5 Model Training and Validation

The dataset was divided into training and testing sets:

- **Training set:** 70%
- **Testing set:** 30%

Cross-validation was used on the training set to prevent overfitting and ensure that the model generalizes well. The model was trained on the TF-IDF features using the Random Forest classifier implemented via Scikit-learn.

3.6 Performance Metrics

To evaluate the performance of the model, the following metrics were calculated:

- **Accuracy:** Proportion of correctly classified messages.
- **Precision:** Proportion of predicted spam that is actually spam.
- **Recall (Sensitivity):** Proportion of actual spam messages correctly identified.
- **F1-score:** Harmonic mean of precision and recall.
- **Confusion Matrix:** Breakdown of predicted vs. actual values.

This comprehensive evaluation ensures that the model is not just accurate but also balanced in its predictions.

3.7 Feature Importance Analysis

After training, feature importance scores were extracted from the Random Forest model. These scores indicate which words (features) contributed most significantly to the spam detection decision. For instance, words like **"free", "win", "prize", "urgent"** were among the top contributors, aligning with known spam patterns.

3.8 Tools and Libraries Used

- **Python 3.9**
- **Scikit-learn** (for model training and evaluation)
- **NLTK** (for preprocessing)
- **Pandas & NumPy** (for data handling)
- **Matplotlib & Seaborn** (for visualization)

4. VECTORIZER

Since machine learning models work with numbers and not text, vectorization is the process of transforming textual data (emails, SMS, etc.) into a structured numerical format. This allows the model to "understand" the text for classification tasks.

Common Types of Text Vectorizers

1. Bag of Words (BoW)

- Converts a collection of text documents into a matrix of token counts.
- Each document is represented as a vector where each dimension corresponds to a word from the corpus vocabulary.
- Does not consider word order or context.
- Example:
  - "Free prize" → [1, 1]
  - "Claim prize" → [0, 1]

2. TF-IDF (Term Frequency-Inverse Document Frequency)

- Measures the importance of a word in a document relative to the entire corpus.
- More sophisticated than BoW because it reduces the weight of commonly occurring words (like "the", "is") and emphasizes rare but potentially informative words (like "free", "prize").
- Formula:
  TF-IDF(t,d)=TF(t,d)×IDF(t)\text{TF-IDF}(t,d)=\text{TF}(t,d)\times\text{IDF}(t)TF-IDF(t,d)=TF(t,d)×IDF(t)
  - TF(t,d): Term Frequency of term *t* in document *d*
  - IDF(t): Inverse Document Frequency of term *t* across all documents

3. Word Embeddings (Advanced)

- Methods like **Word2Vec**, **GloVe**, or **BERT** capture semantic meaning and context.
- More advanced than traditional vectorizers but require more data and computational resources.
- Not commonly used in basic Random Forest models without dimensionality reduction.

5. RESULTS AND DISCUSSION

The Random Forest classifier demonstrated a reliable performance in identifying spam messages. The confusion matrix shown in figure.3 revealed high true positives and true negatives, indicating effective classification of both spam and ham. Precision and recall values were balanced, confirming that the model did not overly favor one class over another.

classification report is:

	precision	recall	f1-score	support
ham	1.00	0.87	0.93	85
spam	0.31	1.00	0.48	5
accuracy			0.88	90
macro avg	0.66	0.94	0.70	90
weighted avg	0.96	0.88	0.91	90

Figure.2. Classification report

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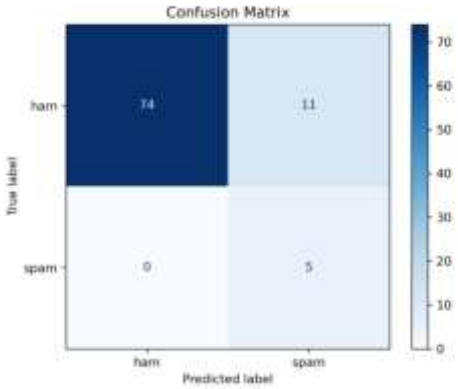


Figure.3. Confusion matrix

The Random Forest classifier achieved an overall accuracy of 88% in spam detection. It performed well on the 'ham' class, with perfect precision (1.00) and a strong F1-score (0.93), correctly identifying most non-spam messages. For the 'spam' class, while recall was perfect (1.00), the precision was low (0.31), leading to a modest F1-score of 0.48. This figure.2 indicates the model successfully detects all spam but also misclassifies many ham messages as spam. The results highlight a class imbalance issue, as ham messages dominate the dataset. Addressing this imbalance through resampling or adjusting class weights could improve spam precision in future work.

6. CONCLUSION

This paper demonstrates the effectiveness of using a Random Forest classifier for spam detection, achieving an accuracy of 87.77%. Compared to traditional models, Random Forest offers robustness, scalability, and high classification accuracy. Future work can involve incorporating deep learning approaches or hybrid ensemble models to further enhance performance. Additionally, adapting the model to real-time systems and multilingual datasets may broaden its applicability.

7. FUTURE WORK

Future directions include:

- Using advanced feature engineering and word embeddings (Word2Vec, BERT)
- Implementing deep learning architectures like LSTM or transformers
- Evaluating on large-scale and multilingual datasets
- Developing a lightweight, real-time implementation for deployment in email or SMS systems.

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