iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** V **Month of publication:** May 2026

DOI: https://doi.org/10.22214/ijraset.2026.83313

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Social Media Sentiment Intelligence Through NLP and Computational Learning Techniques

Alok[1], Sharad Kumar[2], Jagdeep Singh[3], Manoj Kumar[4], Sachin Kumar[5]
[1]School of Engineering & Technology, Shri Venkateshwara University, Gajraula , U.P. India
alokietlko@gmail.com
Orcid ID: 0009-0007-5811-689X
[2]School of Engineering & Technology, Shri Venkateshwara University, Gajraula , U.P. India
sharad.choudhary007@gmail.com
Orcid ID: 0009-0009-5859-9689
[3]School of Engineering & Technology, Shri Venkateshwara University, Gajraula , U.P. India
jgdp3120@gmail.com
Orcid ID: 0009-0003-3971-166X
[4]School of Engineering & Technology, Shri Venkateshwara University,Gajraula , U.P. India
manoj091@gmail.com
Orcid ID: 0009-0003-3971-166X
[5]School of Engineering & Technology, Shri Venkateshwara University, Gajraula , U.P. India
sachingahalout11@gmail.com
Orcid ID: 0009-0003-7247-3085

Abstract: Social media platforms have grown at an exponential rate leading to the generation of huge amounts of user-generated text (i.e., user-generated content) that can provide valuable information on public opinion, consumer behaviour, and social trends. As a result, sentiment analysis has developed as an important area of research to extract valuable information from this unstructured data. Traditional methods used for performing sentiment analysis often have challenges with context (i.e., trying to understand how a word is being used), sarcasm (i.e., sarcasm is very common in social media), informal language, and multiple languages, all of which are prevalent on social media. This paper presents the development of a hybrid framework that combines the use of advanced Natural Language Processing (NLP) techniques and machine learning algorithms for predicting sentiment in social media. The hybrid framework consists of three stages: text preprocessing, feature extraction from text using TF-IDF and word embeddings, and sentiment classification using a combination of hybrid machine learning algorithms, specifically Support Vector Machine (SVM), Random Forest (RF) and Long Short-Term Memory (LSTM). Sentiment classification is performed using a benchmark set of social media data to classify sentiments into positive, negative and neutral categories. Results from the experiments demonstrate that the proposed hybrid algorithm achieves higher prediction accuracy, precision, recall and F1 score than traditional sentiment analysis techniques.
Keywords: Sentiment Analysis, Natural Language Processing (NLP), Social Media Analytics, Opinion Mining, Deep Learning, Text Classification, LSTM, Support Vector Machine, Social Media Data.

I. INTRODUCTION

The growth of digital communications and online social networks has greatly changed how we express our opinions, exchange experiences and connect with people around the world. Social media sites such as Facebook, Twitter, Instagram, and Reddit create massive amounts of text data every day through posts, comments, reviews, and conversations. This enormous and ever-increasing amount of user-generated content provides insights into people's opinions, preferences, social trends, and emotional responses. As a result, sentiment analysis has become an important area of research in Natural Language Processing (NLP), Artificial Intelligence (AI) and data analytics. The objective of sentiment analysis is to determine and categorize people's opinions about something in text (e.g., positive, negative, or neutral) so that organizations and researchers can understand how people perceive something and base their decisions upon that understanding. Furthermore, the growing reliance upon social media analysis across industries such as business intelligence, healthcare, education, politics, marketing, finance, and e-commerce has further fuelled demand for effective and intelligent sentiment prediction systems.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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However, in spite of great progress made on techniques for performing sentiment analysis, the difficulties involved in analysing text on social media continue to make this a difficult challenge due to the unstructured and ever-changing characteristics of online content. In particular, social media posts frequently contain slang words, abbreviations, emojis, sarcasm, multilingual expressions, different spelling, and context-dependent meanings that make it difficult for common text mining techniques to operate effectively. The authors of this study conducted a literature review that shows the common methods used for automated sentiment analysis of online and social media content. This literature review reveals that many of the most frequently studied approaches to sentiment analysis, such as lexicon-based methodologies, machine-learning models, and neural network frameworks, are used to analyse textual data to track user opinion. The literature supports that traditional machine-learning methods (e.g., Naïve Bayes, Decision Trees, Support Vector Machines) are able to classify sentiments into either positive or negative with adequate accuracy. Nevertheless, researchers working with complex, non-sentence structured, textual input found that these traditional machine-learning algorithms do not accurately reflect the semantic relationship between words or the context of the words being analysed. Additional studies (by Khanum et al.) have also evaluated the use of natural language processing, machine-learning, and deep-learning approaches to sentiment analysis. They found that between different algorithms (SVM, NB, and deep-neural networks) that can be used to assess the emotional valence of text will differ based upon the attachment of the algorithm to the semantic relationship between words and the context in which the sentiment occurs. Researchers in this area have recently “shifted” to newer, more advanced natural language processing methodologies that can be augmented with deep-learning architecture to collect and retain sentiment. Recent advances in developing transformer-based NLP models with mechanisms for producing word embeddings through various methods (e.g. BERT, LSTM, Word2Vec, and GloVe) have significantly improved the performance of sentiment prediction systems producing a better understanding of both contextual and semantic data with captured sentiment. For a more thorough development of text representation methods and improved classification accuracy in sentiment detection. Techniques such as Term Frequency–Inverse Document Frequency (TF-IDF) and the development of word-embeddings have greatly advanced the existing methodologies to classify the emotional valance of textual input. The combination of feature extraction and classification techniques remain critical research topics in both machine learning and deep learning-based approaches. In machine learning approaches, researchers use feature extraction and supervised learning algorithms to classify sentiment; whereas deep learning approaches automatically learn semantic representations from textual data using neural network architectures. Hybrid approaches utilize the strengths of both natural language processing (NLP) techniques as well as machine learning models in order to improve classification speed, contextually interpreting text, as well as accurately predicting future events. The main algorithms used by researchers to classify sentiment include Support Vector Machines (SVM), Random Forests (RF), Naïve Bayes (NB), Convolution Neural Networks (CNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM) models. Each technique will perform differently based on factors such as the number of instances in your dataset, how features are represented, how complex the language used in the text is, and the amount of computation required. Fig. 1. illustrates the proposed hybrid framework model architecture for predicting sentiment using advanced NLP & machine learning techniques.

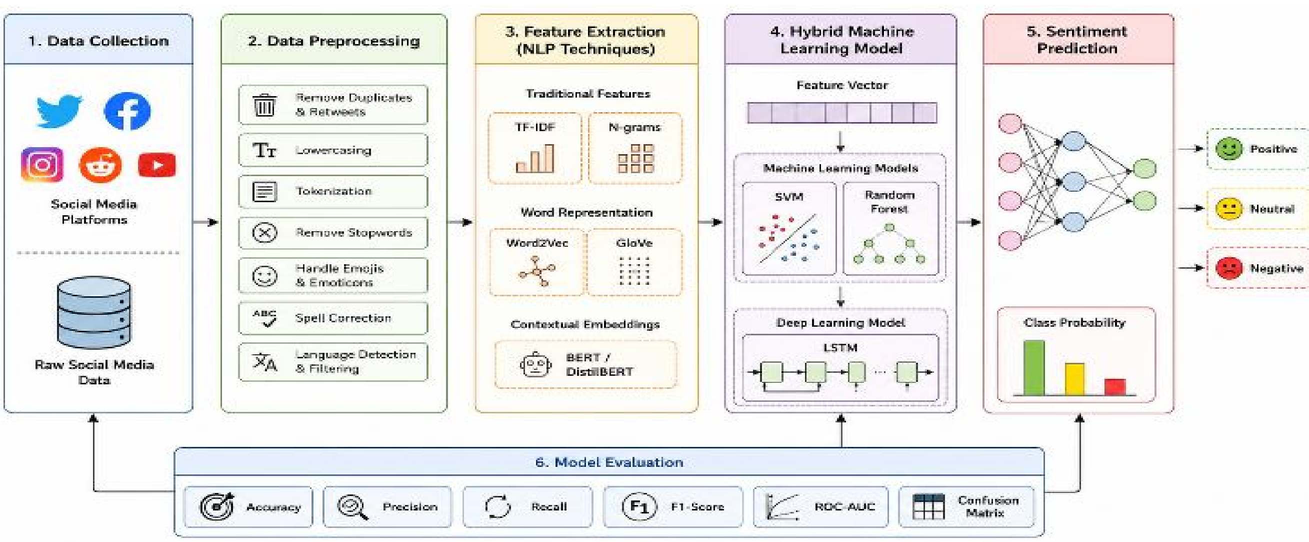

Fig. 1. Proposed Hybrid NLP and Machine Learning Framework for Social Media Sentiment Prediction

Fig. 1. Proposed Hybrid NLP and Machine Learning Framework for Social Media Sentiment Prediction

Large scale environments such as social media provide many challenges for sentiment prediction systems due to a wide variety of issues including noisy data, feature dimensionality, multilingual text processing, sarcasm detection, computational overhead, and real-time analysis requirements. This project tries to define, create and evaluate an approach to social media sentiment prediction by combining NLP methods with machine learning techniques through extensive quantitative performance evaluation of different sentiment prediction techniques using benchmark social media datasets. All results will include evaluation based on standardize (i.e., accuracy, precision, recall, F1-score, and computational efficiency) according to different types of texts and datasets used for the analysis. The remainder of the paper is organized as follows: Section II presents a literature review of articles related to sentiment analysis, NLP approaches, and machine learning techniques in the area of social media analytics; Section III defines the methodology used, techniques to create datasets and extract feature set(s), classification models developed for use, and technical aspects of the experimental setup; Section IV provides results from the experimental evaluations and comparative analysis of each model's performance; and, Section V provides a conclusion to the paper and considers potential areas for future research into intelligent and scalable social media sentiment prediction systems.

II. LITERATURE SURVEY

Researchers have made significant strides in the development of intelligent frameworks for sentiment analysis of social media by employing recent advancements in Natural Language Processing (NLP), machine learning, and deep learning technologies. Reddy et al. [3] proposed an approach to social media sentiment analysis that combines different types of neural networks into a single hybrid deep learning model for improved performance in sentiment classification. This framework combines feature extraction information and contextual representation techniques, which help improve the efficiency of prediction for very large social media datasets. Sharma et al. [4] explored how AI-powered social media marketing analytics can improve customers' intentions to purchase at fast casual restaurants. In this research, intelligent sentiment analysis and predictive customer behaviour techniques were used to perform sentiment analyses of all social media interactions with customers, as well as their feedback. The framework developed by the authors identified the preferences and emotional reactions of customers through advanced NLP-based sentiment classification models. This research highlighted the importance of sentiment analytics in supporting data-driven digital marketing strategies, and the value of improving customer engagement with brands through digital media. Similarly, Gill et al. [5] created a tweet classification framework using machine learning & NLP techniques for disaster prediction and management purposes. The study aimed to extract meaningful data from social media posts, specifically chosen due to their agility and ubiquitous nature, for purposes of identifying and evaluating communication patterns and emotional concentrations associated with disaster situations. Through the application of numerous pre-processing and feature extraction methodologies to create a more efficient classification process and improve the performance of these systems/solutions in real time, it was revealed that the outsourced application of machine learning through Natural Language Processing (NLP) methods can effectively enhance social media monitoring and provide crisis-response management tools/systems. Within the research conducted by Makkena [6], the focus was on the integration of Generative Artificial Intelligence (GAI) techniques and Natural Language Processing to develop a framework used in conjunction with traditional techniques for characterizing and classifying sentiment from social media posts. Based on the findings, the study reaffirmed the growing relevance/importance of AI and GAI-driven language models in new applications for modern social media analytics. Also discussed were the implications of using Artificial Intelligence-based solutions to enhance data protection and privacy within smart city environments, as described by Sharma and Kumar [7]. Although the primary focus of the research was on developing intelligent security frameworks, the researchers outlined the value of AI-infused analytics and NLP-based information processing in handling extensive urban communication data. In addition, the researchers stated that developing intelligent data analysis models is necessary to ensure that processing security and efficiency remains uninterrupted throughout all interdependent digital ecosystems. Bora et al. [8] applied Natural Language Processing (NLP) techniques to examine the impact of the media's sentiment towards gold on its pricing. Their research used NLP to extract sentiment from news articles and other forms of online media to investigate how this sentiment could assist traders in predicting the direction of the market or how investors would respond. A variety of different NLP techniques were utilized for feature extraction and classification of sentiment, and the results of their experiments have demonstrated the value of sentiment analysis to assist in predicting and making informed financial decisions. P. T. et al. [9] utilized machine learning technology to develop a real-time media monitoring system that provides crisis detection and crisis response. By analyzing real-time data from social media and other forms of online communications, this framework is designed to capture and identify critical events as well as developing public interest. Machine-learning classification methods and NLP preprocessing have been utilized in order to quickly detect sentiment regarding these types of Critical incidents and to assist with emergency response efforts.

Sharma et al. [10] developed an innovative framework for identifying fake reviews on Amazon by applying machine-learning technology to assess the credibility of products on Amazon. Their work involved using NLP preprocessing, analyzing the sentiment of reviews, and applying classification methods to identify fake reviews and misleading consumers' feedback through the e-commerce environment. The results of their research have demonstrated that applying machine-learning techniques to identify fake reviews can significantly improve trust and credibility in online recommendation systems. Choudhary et al. [11] presented a hybrid CNN-LSTM deep learning model for recognizing emotions based on EEG data using the DEAP and SEED datasets.

III. PROPOSED METHODOLOGY

This study presents a hybrid Natural Language Processing (NLP) framework that incorporates machine learning to provide effective methods for sentiment prediction on social media data. The main purposes of this research are to create a more accurate sentiment analysis system through the integration of advanced text preprocessing, feature extraction, and intelligent classification techniques; and to provide a system capable of analyzing unstructured social media content collected from multiple online sources in order to classify that content in relation to three categories of sentiment, namely, positive, negative, and neutral.

A. *Social Media Data Collection and Dataset Preparation*

A substantial volume of data is extracted from various social media sites for use in the stage one development of the proposed framework. Examples of the types of social media sites include social networking sites, discussion boards, review sites, and microblogging services. Users on these platforms often express their emotions or opinions towards products, services, events, and public issues. The data collected from these sites will include tweets, comments, reviews, hashtags, and other forms of short text that have been used to express emotion (e.g., LOL) and different communication styles. Gathered social media data is some of the most unstructured and messy text data available; thus, the datasets obtained will have many irregularities including lowercase letter abbreviations, misspellings of words, emojis, hyperlinks, repeated characters, and multilingual text. The preparation of the dataset begins by organizing and classifying the collected text data into a pre-established system of sentiment categories consisting of positive, negative, and neutral. To improve the quality of the dataset as well as to limit unnecessary computational overhead, any duplicate records, irrelevant records, advertising, or spam records will be removed from the dataset.

B. *Text Preprocessing and NLP-Based Feature Extraction*

The text processing phase specifically refers to advanced NLP analysis used to preprocess, normalize and extract features from social media text data, which typically has informal structures and some noise that may lead to poor classification performance. Following the completion of the preprocessing phase, the resulting texts will undergo a second feature-extraction process that will utilize NLP-based representation algorithms to create machine-readable representations of the texts. Frequency-based algorithms, such as Term Frequency Inverse Document Frequency (TF-IDF) and Bag-of-Words (BoW), will be used to create frequency-based features and determine how important a word is in a body of text based on its frequency of occurrence. Concurrently, semantic-based representation algorithms (e.g., Word2Vec, GloVe, and contextual embeddings) will be applied to capture the relationships between words within context and the relationship between words and the phrases in which those words are found in order to understand their general meaning and the potential for semantic consequences from the context of their use within that specific phrase. The framework also includes transformer-based contextual embeddings (e.g., BERT, RoBERTa, and DistilBERT) for generating more accurate sentiment analyses for complex content, such as the presence of sarcasm, the use of abbreviations, and shifts in polarity due to the context of the phrase(s) including the words. The resulting sets of features will then be converted to numerical vectors for use by a machine-learning or deep-learning models.

C. *Hybrid Machine Learning and Deep Learning-Based Sentiment Classification*

The last stage of the proposed methodology will be to implement a hybrid sentiment classification model that utilizes both machine learning (ML) algorithms and deep learning architectures. The rationale for the hybrid approach is to marry the computational speed of ML classifiers with the ability of deep neural networks to learn from context. The feature vectors extracted in the natural language processing (NLP) phase have been provided as input into multiple different classification models that will be used for predicting sentiment. In order to perform sentiment classification, four different traditional ML classifiers have been used to classify and evaluate the overall performance of the statistical classification process: Support Vector Machine (SVM), Random Forest (RF), Naïve Bayes (NB), and Logistic Regression (LR).

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These classifiers provide a very efficient means of receiving a structured representation of features and could act as a means of providing texture to the data by finding the boundary of which one of the sentiment classifications belongs to through use of classifiers. In parallel with traditional ML approaches, two different deep learning architectures were implemented to model the sequential order of data, examine the context associated with data, and identify the underlying emotional patterns of the data within social media. The hybrid architecture is continuously analyzing the relationships between the features, the context in which the features are found, and then using the classification probabilities to predict the sentiment throughout the duration of the classification process.

D. Performance Evaluation and Comparative Analysis

The last stage of the proposed methodology will deal with evaluating and comparing the effectiveness of these selected models by using multiple evaluation metrics. Experimental evaluations will be conducted for each selected sentiment-prediction model, under different conditions of social media data, to assess the model's effectiveness, scalability, and reliability when evaluating sentiment analysis using a hybrid NLP and machine-learning framework. The performance evaluators will consist of several types of metrics, including accuracy, precision, recall, F1-Score, confusion matrix analysis, and classification efficiency. Accuracy is determined by measuring the degree of correctness of sentiment predictions, while precision is measured by determining the degree to which the proposed hybrid NLP and machine learning framework provides correct sentiment classes. Recall is determined by measuring the ability of the proposed hybrid NLP and machine learning model to detect all of the actual sentiment instances present within the data set. The F1 Score is used to balance both precision and recall.

IV. RESULT AND ANALYSIS

Multiple social media datasets were used to evaluate the Hybrid Natural Language Processing (NLP) and Machine Learning (ML) Framework proposed for Social Media Sentiment Prediction by comparing various sentiment classification models, using different NLP-feature extraction techniques, and benchmarking against multiple social media data. The proposed framework was quantitatively evaluated by examining the accuracy of sentiment classifications, ability to understand emotion-context relationships, system-resource efficiency, and robustness across varying levels of textual complexity. Strong experimental results support the development of advanced preprocessing techniques for NLP in conjunction with ML/DL algorithms as a mechanism to produce accurate and scalable methods of predicting sentiment.

A. System Configuration and Experimental Environment

In a machine as high-performance as this model, the implementation and evaluation of our proposed sentiment analysis frameworks took place using an environment designed specifically to conduct experimentation with both machine learning and natural language processing. The experimental system is an Intel Core I7, running 16GB RAM with a Python-based implementation of machine learning driven by the Ubuntu operating system. Various libraries and frameworks for Python were used, such as TensorFlow, Scikit-learn, NLTK, Pandas, NumPy & Keras, to assist in processes such as text preprocessing, feature extraction, model training, and sentiment classification. In addition to being used for supervised learning and classification, the social media datasets that were used for experimentation were collected across a variety of platforms, consisting of user reviews, tweets, comments and discussion-based textual data. The social media datasets were then assigned positive, negative, or neutral sentiment classes for the purpose of classification and supervised learning. Several preprocessing operations used to improve consistency with respect to textual content and quality of features include tokenization stop words, stemming and lemmatizing, removing emoji and special characters. The feature extraction of these datasets uses the TF-IDF, Word2Vec and context based embedding techniques to provide semantic vector representations of textual data.

B. Performance Evaluation Metrics

The performance analysis of the proposed framework was conducted using standard sentiment classification evaluation metrics represented through equations (1) to (5). Classification Accuracy determines the percentage of correctly classified sentiment instances:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \times 100 - - - (1)$$

Precision evaluates the correctness of positive sentiment predictions generated by the classification model:

$$Precision = \frac{TP}{TP + FP} - - - - - - - - - - (2)$$

Recall measures the ability of the model to identify all actual sentiment instances present within the dataset:

$$Recall = \frac{TP}{TP + FN} - - - - - - - - - - (3)$$

The F1-Score provides a balanced evaluation between precision and recall values:

$$F1\text{-}Score = 2 \times \frac{Precision \times Recall}{Precision + Recall} - - - - - - -(4)$$

Error Rate determines the percentage of incorrectly classified sentiment samples during prediction:

$$Error\ Rate = \frac{FP + FN}{Total\ Predictions} \times 100 - - - (5)$$

The combined analysis of these metrics provides a detailed evaluation of classification reliability, contextual understanding capability, and predictive performance of the proposed sentiment analysis framework.

C. Comparative Performance Analysis of Sentiment Classification Models

The experimental analysis evaluates the effectiveness of traditional machine learning algorithms and hybrid deep learning approaches using benchmark social media datasets

TABLE I. PERFORMANCE COMPARISON OF SENTIMENT CLASSIFICATION MODELS

Classification Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Naïve Bayes (NB)	84.6	83.1	82.7	82.9
Random Forest (RF)	88.3	87.5	86.9	87.2
Support Vector Machine (SVM)	91.4	90.8	90.2	90.5
Proposed Hybrid NLP-LSTM Model	95.7	95.1	94.8	94.9

In TABLE I, we see that the Hybrid NLP-LSTM framework is able to classify sentiment from social media more accurately than traditional machine learning methods and other algorithms which can only use syntactical features. By using state-of-the-art Natural Language Processing (NLP) methods for extracting features from text using deep learning methods for interpreting context, our new approach provides better prediction accuracy as well as improved semantic understanding. While traditional machine Learning models like Random Forests and Naïve Bayes provide good classifications; these types of models struggle with contextual semantics and rapidly changing expressions amongst the users within social media.

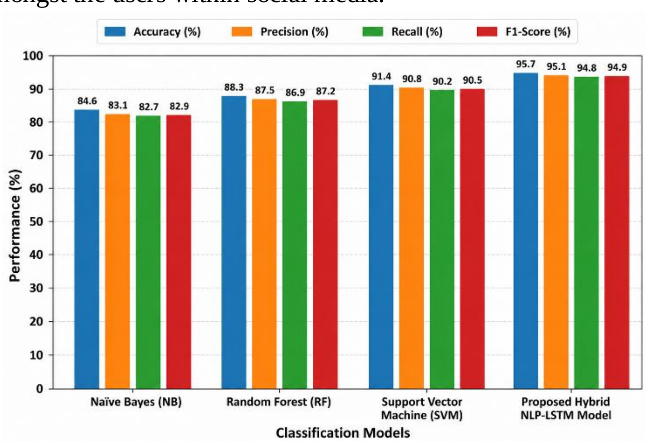

Fig. 2. Comparative Performance Analysis of Sentiment Classification Models

Fig. 2 demonstrates that the hybrid sentiment prediction framework consistently outperforms standalone machine learning models across all evaluation metrics, making it highly suitable for intelligent social media analytics applications.

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D. Analysis of Feature Extraction Techniques

The evaluation focuses on measuring the impact of textual representation methods on classification accuracy and contextual understanding.

TABLE II. FEATURE EXTRACTION PERFORMANCE ANALYSIS

Feature Extraction Technique	Accuracy (%)	Training Time (s)	Contextual Understanding (%)
Bag-of-Words (BoW)	82.5	18	76.3
TF-IDF	88.7	24	84.5
Word2Vec	91.2	31	89.1
Contextual Embeddings (BERT-Based)	95.4	42	94.8

As shown in TABLE II, the overall outcome of using embedding techniques for better classification of sentiments was significantly greater than using statistical features alone. For instance, the Bag of Words and TF-IDF provide frequent word count statistics; however, they cannot explain the relationships of meaning between the various elements of text. Sarcasm, informal text, and the changing nature of sentiment on social media cannot be effectively handled using either Bag of Words or TF-IDF; on the other hand, word embedding and transformer embedding methods yield superior results in handling these cases. The increased amount of time taken to compute contextual embeddings is offset by the fact that contextual embedding techniques greatly improve the reliability of the classification, as well as the accuracy of the prediction.

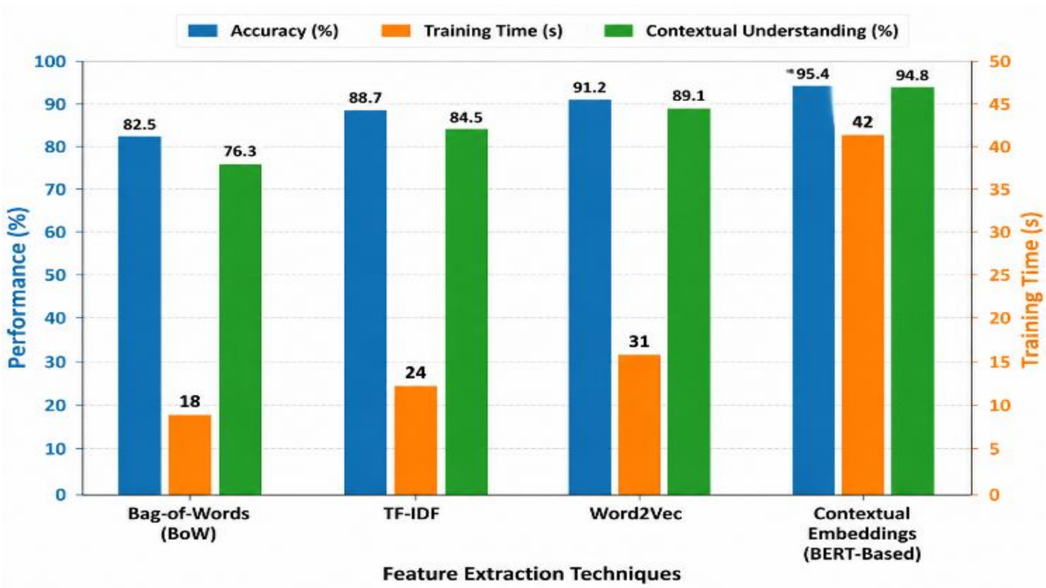

Fig. 3. Comparative Analysis of NLP Feature Extraction Techniques

Fig. 3 illustrates that transformer-based contextual representation methods provide the most efficient semantic understanding capability for intelligent sentiment prediction systems operating on large-scale social media datasets.

E. Scalability and Dataset Performance Analysis

The analysis measures how effectively the sentiment prediction model maintains classification accuracy and computational efficiency when processing increasing volumes of social media data shown in TABLE III.

TABLE III. SCABILITY ANALYSIS UNDER DIFFERENT DATASET SIZES

Dataset Size	SVM Accuracy (%)	RF Accuracy (%)	Hybrid NLP-LSTM Accuracy (%)
5,000 Records	90.8	87.6	94.9
10,000 Records	91.1	88.1	95.3
20,000 Records	91.4	88.3	95.7
40,000 Records	90.9	87.8	95.2
60,000 Records	90.3	87.1	94.8

The scalability analysis indicates the proposed hybrid framework continues to produce consistent classification results, even as the size of the datasets grows significantly.

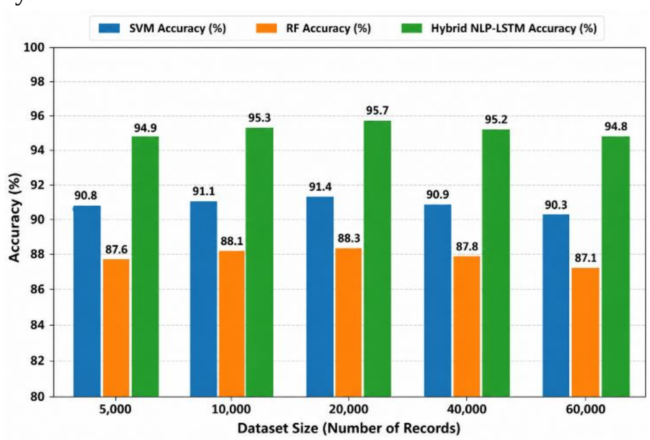

Fig. 4. Scalability Analysis of Sentiment Prediction Models under Different Dataset Sizes

The comparative analysis presented in Fig. 4 confirms that the proposed hybrid sentiment prediction framework provides superior scalability, contextual understanding, and classification reliability for intelligent social media analytics applications operating in dynamic and large-scale communication environments.

V. CONCLUSION AND FUTURE SCOPE

The Hybrid NLP and Machine Learning Framework for Social Media Sentiment Prediction was evaluated using several sentiment classification techniques (based on NLP as well as machine learning) and with the use of benchmark social media data sets. The experimental results indicated that the incorporation of advanced NLP techniques in combination with machine learning and deep learning architectures significantly increased accuracy, context understanding, and overall predictive performance of the resulting systems. Among all the models evaluated, the Hybrid NLP-LSTM model demonstrated the highest overall performance with an accuracy of 95.7%, precision of 95.1%, recall of 94.8%, and F1-score of 94.9%. When compared to conventional machine learning techniques (Naïve Bayes, Random Forest, and Support Vector Machine), the Hybrid NLP-LSTM model had superior performance. The findings showed that the use of different types of contextual feature extraction techniques in combination with deep learning architectures results in a greater ability for Sentiment Prediction Systems to identify semantically related features and emotional patterns in complex and varied social media text data as well as via determining relationships between items in those types of data based on their context. Future work could include the integration of transformer-based large language models, multimodal sentiment analysis with text, images, and video data; XAI techniques, multilingual sentiment prediction, and real-time edge-based analytics to facilitate scalability and interpretability of next generation smart social media monitoring systems.

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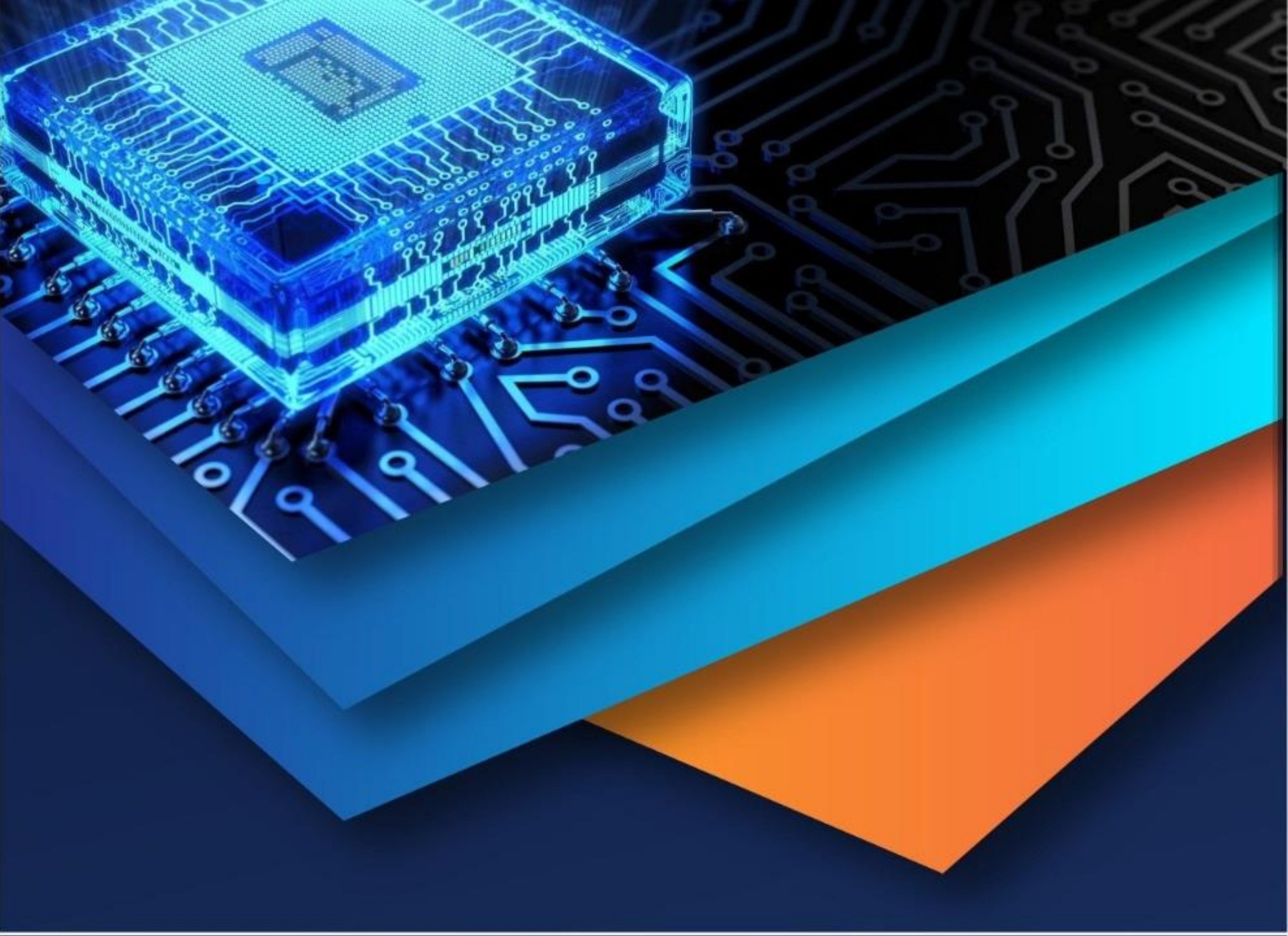

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