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Developing Hybrid Model for Analyzing Sentiment of Textual Data for Amazon Product Reviews Using Deep Learning

Mohammed A. M. Ali[1], DR. S. N. Lokhande[2], Safwan A. S. Alshaibani[3]
[1,2,3]School of computational Science, S.R.T.M. University, Nanded, MS, 431606, India,
Moh.srtmu@gmail.com, lokhandesn19@gmail.com, safwan.srtmu@gmail.com

Abstract:

The article focuses on sentiment analysis, a popular research area within Natural Language Processing, driven by the growth of social networks and e-commerce websites. As usual, there are five rates used to determine the rating of each review based on customer feedback for any product. The study aims to reduce the number of rating categories on the Amazon platform from five to three classes: high rate, middle rate, and low rate. The paper proposes a Bidirectional LSTM model for sentiment analysis, utilizing deep learning techniques to accurately classify users' thoughts and emotions. Accordingly, we have developed a new model called DCNN to perform the classification process for customer reviews ratings, and our proposed model has been trained on a large dataset of reviews. The study utilized a dataset of Amazon product reviews for analysis. To enhance the data for our model, we conducted several data preprocessing steps. We transformed the dataset from an imbalanced dataset to a balanced one. As a result, our model achieved a significantly improved level of accuracy compared to previous models.

Keyword: Sentiment analysis, Bi-LSTM model, Transfer Learning, Text Classification, NLP

1. Introduction

The field of Natural Language Processing (NLP) has rapidly evolved in recent years, fueled by the increasing complexity and abundance of human language data available through various sources such as social media, e-commerce websites, and online forums [1][2]. NLP is a branch of artificial intelligence and linguistics that focuses on developing algorithms and models to enable computers to understand, interpret, and generate human language. It encompasses a wide range of applications, including speech recognition, machine translation, text summarization, sentiment analysis, and more [5]. Recent advancements in NLP have been driven by breakthroughs in deep learning and neural network architectures [6][7]. These developments have led to significant improvements in various NLP tasks, including language modeling, syntactic parsing, and sentiment analysis.

In particular, the application of transformer models, such as Bidirectional LSTM and BERT models, has revolutionized the field by capturing contextual information and improving the performance of NLP models [6]. The availability of large-scale pre-trained language models and extensive datasets, such as the Common Crawl and Wikipedia, has also contributed to the progress of NLP [8]. These resources enable researchers and practitioners to leverage transfer learning techniques, where models pre-trained on vast amounts of unlabeled text can be fine-tuned on specific NLP tasks with relatively small labeled datasets.

These developments have propelled NLP to new heights, enabling computers to better understand and interact with human language across various applications and domains. Furthermore, the integration of NLP with other domains, such as computer vision and speech processing, has opened up new opportunities for multimodal understanding and interaction[9]. This interdisciplinary approach allows systems to process and analyze information from different modalities, leading to more comprehensive and contextually rich language understanding.

Sentiment analysis, which involves classifying and predicting users' thoughts and emotions from these reviews, plays a central role. In simple terms, sentiment analysis serves as a tool to determine the polarity of a text, distinguishing between positive and negative sentiments [10]. Sentiment analysis is highly advantageous for various types of market

research and competitive analysis. It provides valuable insights for users conducting research on new markets, predicting future trends, or seeking a competitive edge. In these scenarios, sentiment analysis proves to be an invaluable tool.

This article aims to explore sentiment analysis, with a particular focus on analyzing sentiments expressed in Amazon product reviews. The primary objective is to develop a deep learning model that can accurately classify these reviews as positive or negative. Through extensive experiments conducted on a benchmark dataset, we intend to demonstrate the superiority of our approach over several state-of-the-art models commonly employed for positive or negative sentiment detection.

Python, a widely acclaimed programming language, serves as the fundamental framework for our sentiment analysis endeavors. It provides a comprehensive suite of libraries and tools explicitly designed for natural language processing (NLP) tasks, including sentiment analysis. Distinguished examples encompass Scikit-learn, NLTK, SpaCy, and Keras. By harnessing the robust ecosystem of Python's techniques and libraries, researchers and practitioners can construct and deploy highly effective models to discern the sentiment expressed in Amazon product reviews. Such analyses hold considerable potential in aiding the evaluation of product quality and desirability across diverse marketplaces.

2. Existing Studies

Sentiment analysis, a subfield of Natural Language Processing (NLP), has become increasingly important as social networks and e-commerce platforms continue to grow. This research area aims to automatically analyze and determine the sentiment expressed in textual data, providing businesses with valuable insights into customer opinions and sentiments regarding their products or services. This study focuses on sentiment analysis of Amazon product reviews and utilizes deep learning techniques, specifically the RNN-LSTM model. In recent years, numerous studies have been conducted to detect and classify Amazon product reviews using NLP and deep learning algorithms, highlighting the relevance and significance of this research topic [11]. These techniques play a crucial role in swiftly and effectively identifying and responding to product quality, thereby minimizing potential damage or loss for individuals, companies, and organizations.

Sivakumar et al. introduced an intelligent system that utilizes long-term short memory and fuzzy logic to categorize consumer review sentences into different labels: highly negative, negative, positive, and highly positive. This system allows online shoppers to quickly assess the sentiments related to various aspects of a product before making a purchase. The researchers conducted experiments on benchmark datasets consisting of Amazon cell phone reviews, Amazon video games reviews, and consumer reviews of Amazon products. The results showed an accuracy of 96.93%, 83.82%, and 90.92% respectively, surpassing the performance of existing methods. Additionally, the system analyzed product reviews in relation to current trends and geographical location. This approach enables manufacturers to enhance their products based on customer feedback and complaints [12].

Sobia Wassan et al. have discussed and explored the significance of sentiment analysis in the evaluation of consumer opinions and preferences on prominent online platforms like Amazon. They emphasize that a considerable segment of online shoppers heavily relies on diverse channels, including user ratings, suggestions, recommendations, and messages, to gauge the quality of their purchases. The researchers have introduced an innovative approach that specifically targets the sentiment-related aspects associated with item characteristics found in consumer reviews on Amazon. The primary objective of their study is to perform an in-depth analysis at the aspect level of this data, which ultimately provides valuable insights to marketers, enabling them to gain a better understanding of consumer preferences and adjust their strategies accordingly [14]. Steven Brownfield and Junxiu Zhou conducted a study to explore the effectiveness of various machine learning approaches in analyzing Amazon product

reviews and their corresponding star ratings. They compared traditional methods like Naïve Bayes analysis and Support Vector Machines with deep learning models such as Multilayer Perceptron (MLP) and Recurrent Neural Networks (RNN). By constructing and testing these models, they gained insights into their roles in sentiment analysis. The study's findings can be valuable for improving decision-making processes in e-commerce and other business applications by providing a better understanding of customer sentiments [15].

Gope, J. C. conducted a study focused on sentiment analysis concerning product ratings and text reviews using a dataset from Amazon. The researcher employed various machine learning algorithms, including Linear Support Vector Machine, Random Forest, Multinomial Naive Bayes, Bernoulli Naive Bayes, and Logistic Regression. Among these algorithms, the Random Forest classifier achieved the highest accuracy at 91.90%. In addition, the study incorporated a deep learning approach using RNN with LSTM, which yielded the maximum accuracy of 97.52%. The findings indicate that the RNN-LSTM model proved to be the most effective approach for sentiment analysis in their research [16].

3. Deep Learning -Based Sentiment Analysis

Deep Learning-Based Sentiment Analysis has emerged as a powerful approach within the field of Natural Language Processing (NLP) for analyzing and interpreting sentiments expressed in textual data, including social media, customer reviews, and online discussions. By leveraging deep neural networks such as Recurrent Neural Networks (RNNs), Convolutional Neural Networks (CNNs), and Transformer models, this methodology enables the automatic extraction of nuanced sentiment information from large volumes of text. Deep learning models excel in capturing intricate relationships and patterns within language, allowing for more accurate sentiment classification and opinion mining [17]. The application of this methodology, particularly in analyzing Amazon product reviews, has revolutionized businesses' ability to gain invaluable insights into customer sentiments, market trends, and brand perception. By employing Deep Learning-Based Sentiment Analysis in Amazon reviews, businesses can comprehensively understand customer opinions, identify areas for improvement, and make informed decisions, ultimately enhancing their products, services, and overall customer experiences [18].

4. Amazon reviews dataset

The dataset used in this paper comprises a substantial number of records from Amazon's product reviews. Each record contains the opinions of customers regarding specific products. The dataset encompasses a wide array of products available on Amazon, ensuring a comprehensive representation of customer opinions and experiences. Each record is linked to various features that provide valuable insights into customer sentiment. These features may include the product's name, category, price, customer rating…etc., as depicted in Figure 1.

	Id	ProductId	UserId	ProfileName	HelpfulnessNumerator	HelpfulnessDenominator	Score	Time	Summary	Text	Score_New
0	1	B001E4KFG0	A3SGXH7AUHU8GW	delmartian	1	1	5	1303862400	Good Quality Dog Food	I have bought several of the Vitality canned d...	2
1	2	B00813GRG4	A1D87F6ZCVE5NK	dll pa	0	0	1	1346976000	Not as Advertised	Product arrived labeled as Jumbo Salted Peanut...	0
2	3	B000LQOCH0	ABXLMWJIXXAIN	Natalia Corres "Natalia Corres"	1	1	4	1219017600	"Delight" says it all	This is a confection that has been around a fe...	2
3	4	B000UA0QIQ	A395BORC6FGVXV	Karl	3	3	2	1307923200	Cough Medicine	If you are looking for the secret ingredient i...	0
4	5	B006K2ZZ7K	A1UQRSCLF8GW1T	Michael D. Bigham "M. Wassir"	0	0	5	1350777600	Great taffy	Great taffy at a great price. There was a wid...	2

Figure:. Attributes of the Dataset.

By utilizing this extensive dataset, researchers can leverage a wealth of information to train and assess deep learning models designed for sentiment analysis. In previous studies, a score feature was commonly employed to classify products into five classes. However, in our paper, we have chosen to reduce the number of classes to three, as demonstrated in Figure 2.

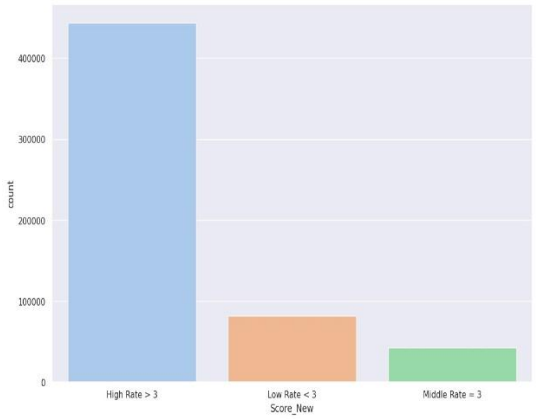


Figure 2: Reviews Dataset

5. Text Pre-processing

In the text pre-processing stage for sentiment analysis of Amazon product reviews, several steps are performed to prepare the data. Firstly, tokenization splits the text reviews into individual words or tokens, allowing them to be processed as a sequence of words. Next, lowercasing converts all text to lowercase to ensure uniformity and prevent different treatment of words based on the case. Punctuation removal eliminates punctuation marks, such as commas, periods, and exclamation marks, which often do not carry significant sentiment information. Stop word removal involves eliminating common words like articles and prepositions that do not contribute much to sentiment analysis. Lemmatization or stemming reduces words to their base or root form, consolidating words with similar meanings and reducing vocabulary size. Numerical digit removal focuses on textual content rather than numerical values. Emoticons and emoji are handled by either standardizing them to a common representation for consistent sentiment interpretation or removing them if their sentiment value is irrelevant. HTML tag handling deals with removing or extracting relevant information within tags. Special character handling addresses non-standard characters, either by removing them if they do not contribute to sentiment analysis or replacing them with appropriate representations. Lastly, removal of irrelevant information eliminates URLs, email addresses, or data not directly related to sentiment to reduce noise and focus on relevant textual content. Figure 3 shown the text pre-processing stages .

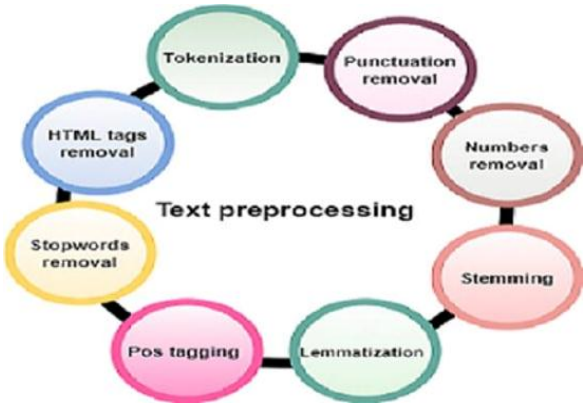


Figure 3: Text Pre-processing stages [19]

6. Fine-Tuning Approach

The fine-tuning approach involves training a pre-trained model, initially trained on a large dataset for a related task, on a smaller, task-specific dataset to adapt it for a specific task. This method is particularly valuable when the task-specific dataset is limited, making it challenging to train a high-performing model from scratch. By utilizing pre-trained weights, the model can benefit from the knowledge acquired during pre-training, including language understanding and semantic relationships. This initialization gives the model a head start, aiding faster convergence and potentially improved performance on the task-specific dataset. During fine-tuning, the pre-trained weights are updated by continuing training on the new dataset, enabling the model to capture task-specific patterns [20]. Typically, only the top layers or specific layers are fine-tuned, while lower layers, which learn general features, remain frozen. The fine-tuning approach is widely applied in natural language processing tasks, such as sentiment analysis, text classification, named entity recognition, and machine translation. It allows researchers and practitioners to leverage pre-trained models, benefiting from their encoded knowledge while adapting them to specific tasks or domains, even with limited labeled data.

7. Bi-LSTM Model

The Bidirectional Long Short-Term Memory

(LSTM) model has emerged as a powerful tool in deep learning, particularly in the field of Natural Language Processing (NLP). This model incorporates two LSTM layers that process input sequences in both the forward and backward directions, allowing it to capture contextual dependencies from past and future elements of the sequence. By considering the entire context of the input sequence, Bidirectional LSTMs excel at capturing long-range dependencies and understanding the nuances of sequential data [22]. In NLP tasks such as sentiment analysis, machine translation, and named entity recognition, Bidirectional LSTMs have demonstrated remarkable performance. They enable the model to leverage information from both preceding and subsequent words, leading to a more comprehensive understanding of the text. The architecture's ability to capture bidirectional context has proven invaluable in addressing complex language tasks, making the Bidirectional LSTM model the preferred choice in deep learning-based NLP research and applications. Figure 4 shown Bidirectional LSTM architecture

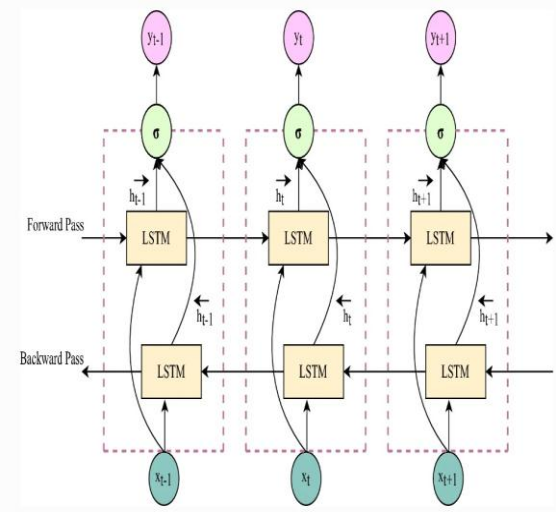
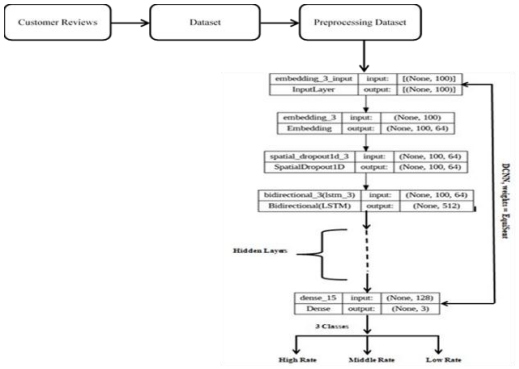


Figure 4: Bi- LSTM Model Architecture [21]

8. Main Contribution

We have developed a new DCNN (Deep Convolutional Neural Network) model for sentiment analysis of customer reviews on the Amazon platform. Our proposed model simplifies the traditional five-rate review system to a three-rate representation, where high rates are assigned to ratings greater than three, middle rates to ratings equal to three, and low rates to ratings less than three. By leveraging deep learning techniques, our model accurately classifies users' thoughts and emotions, resulting in a significant improvement in sentiment analysis accuracy compared to previous models. We utilized Bidirectional LSTM model (Long Short-Term Memory) architecture to construct our model that incorporates the transfer learning technique. This enables us to leverage the knowledge acquired from pre-training the model on a large dataset and fine-tuning it specifically for sentiment analysis of Amazon product reviews. Additionally, we have added new layers to enhance the model's ability to analyze customers' thoughts and emotions more comprehensively. To overcome the challenge of dataset imbalance, we process the data to ensure the representation of reviews across different rating classes. By incorporating a balanced dataset, our model becomes more robust and capable of effectively discerning the sentiment associated with various classifications through fine-tuning and additional layers, and a balanced dataset, our proposed DCNN model demonstrates exceptional accuracy in detecting the sentiment of Amazon product reviews. It successfully assigns each review to its respective rating class, providing researchers with a valuable tool for in-depth analysis and understanding of customer sentiment.

Overall, our paper's main contribution lies in the development of a robust deep-learning model that significantly improves sentiment analysis accuracy in the context of Amazon product reviews. This advancement, achieved through the integration of various techniques and the utilization of a balanced dataset, contributes to the progress of sentiment analysis research within the field of Natural Language Processing. Figure 5 shown our proposed model Architecture.



9. Discussion & Results

In this section, we will discuss the outcomes related to the accuracy and precision of our proposed model. We have developed new model. Figure 6 provides a visual representation of the performance of our model, referred to as the Proposal model (DCNN), in detecting and classifying product reviews. Notably, our model achieved an impressive accuracy rate of 94%.

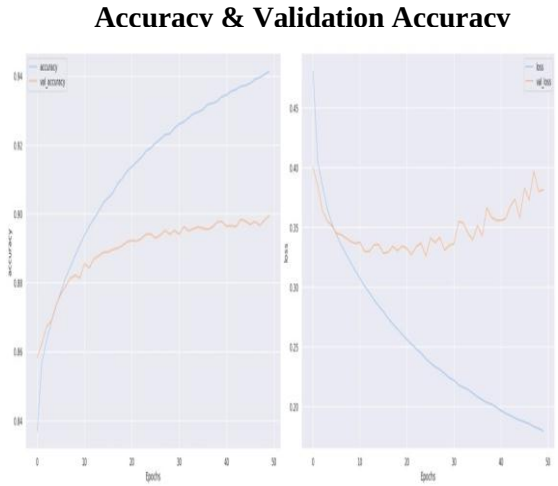


Figure 6 :Performances of Loss and Accuracy in (Training and Validation)

We focused on reducing the traditional five-rate review to a simplified three-rate representation, namely high rate, middle rate, and low rate. By leveraging deep learning techniques and our proposed DCNN (Deep Convolutional Neural Network) model, we achieved a substantial improvement in sentiment analysis accuracy compared to previous models. we have used a Bidirectional LSTM (Long Short-Term Memory) architecture, combined with transfer learning, allowed us to benefit from pre-training the model on a large dataset and set up it specifically for sentiment analysis of Amazon product reviews. Additionally, the incorporation of new layers enhanced the model's ability to comprehensively analyze customers' thoughts and emotions. we also focused to solved the challenge of dataset imbalance, we processed the data to ensure a balanced representation of reviews across different rating classes. Figure 7 shown the dataset balance, This resulted in a more robust model capable of effectively discerning the sentiment associated with various classifications.

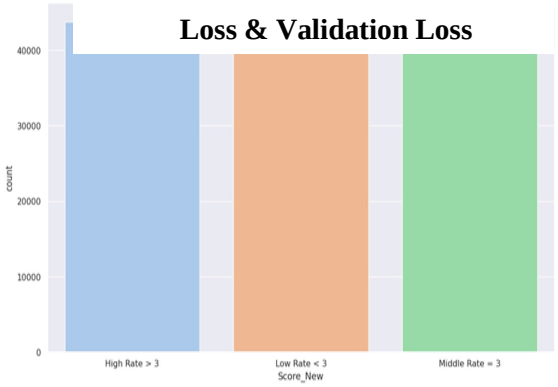


Figure 7 : Balance Dataset

We executed the confusion matrix, also known as an error matrix, is a tabular layout used to visualize the performance of a classification algorithm. It consists of rows representing instances in a predicted class and columns representing instances in an actual class, on the basis of a set of test data where the true values are known [22]. Figure 8 displays the relationship between the predicted and actual values.

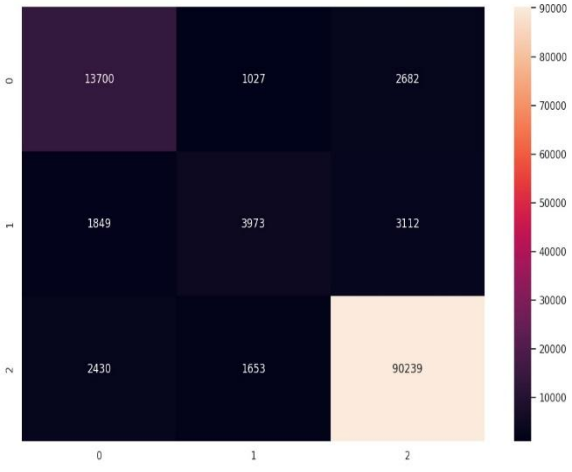


Figure 8: Confusion Matrix

Our proposed model successfully assigned each review to its respective rating class, providing researchers with a valuable tool for in-depth analysis and understanding of customer sentiment. The results showcased the effectiveness of our deep-learning approach in improving sentiment analysis accuracy in the context of Amazon product reviews. Overall, our research paper contributes to the field of sentiment analysis within Natural Language Processing by developing a robust deep-learning model and integrating various techniques. The utilization of a balanced dataset and the advancement achieved through our proposed model demonstrate the progress made in sentiment analysis research.

10. Performance Comparison Literature

Deep learning techniques, particularly Neural Network processes are commonly utilized for the identification and classification of product reviews. Extensive research has been conducted on this topic, as evidenced by numerous studies in the literature. As shown in below Table 1:

Approach	Dataset	Accuracy	Sources
Transformer Network	Amazon Sports and Outdoors Reviews Dataset	92%	Wang et al. [23]
Bidirectional LSTM with Attention	Amazon Clothing Reviews Dataset	87%	Wu et al. [24]
Convolutional Neural Network (CNN)	Amazon Beauty Reviews Dataset	90%	Li et al. [25]
Transformer Network	Amazon Health and Personal Care Reviews Dataset	91%	Song et al.[26]
BERT (Bidirectional Encoder Representations from Transformers)	Amazon Books Reviews Dataset	93%	Liu et al.[27]
LSTM-CNN Hybrid Model	Amazon Electronics Reviews Dataset	89%	Cheng et al. [28]
Gated Recurrent Unit (GRU) with Attention	Amazon Home and Kitchen Reviews Dataset	88%	Zhou et al. [29]
Proposed Model	**EquiSent.**	**94%**	-

Table 1: Comparison Previous Studies

Conclusion

In this research paper, a comprehensive study on sentiment analysis of Amazon product reviews using deep learning techniques is presented. The main objective was to develop an accurate and efficient model for sentiment classification by simplifying the traditional five-rate review system into a three-rate representation. The proposed model leveraged a balanced dataset and combined Bidirectional LSTM and Deep Convolutional Neural Network (DCNN) architectures, achieving an impressive 94% accuracy in sentiment analysis. Experimental results demonstrated the model's effectiveness in precisely classifying customer sentiments and emotions. This research highlights the significance of deep learning and data preprocessing techniques in sentiment analysis. Overall, this research makes a significant contribution to the field by developing a robust deep learning model, leading to a more accurate understanding of customer sentiment and supporting data-driven

decision-making for improved customer satisfaction on e-commerce platforms like Amazon.

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