Integrating Fuzzy Logic into Lexicon-Based Sentiment Analysis: A Hybrid Framework

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doi: https://doi.org/10.21467/proceedings.7.6.37

Abstract

Sentiment analysis, a fundamental natural language processing (NLP) task, aims to classify textual data into positive, negative, or neutral sentiments. Traditional lexicon-based methods rely on predefined sentiment dictionaries to assign polarity scores, but they often struggle with ambiguous, mixed, or context-dependent sentiments. To address this limitation, fuzzy logic-integrated approach has been proposed here for sentiment classification. Fuzzy logic offers a flexible and human-like reasoning approach capable of handling uncertainty and partial truths, making it well-suited for nuanced sentiment assessment. This paper presents a hybrid model that utilizes fuzzy logic to polish sentiment classification. Experimental results demonstrate that combining fuzzy logic with lexicon-driven method can significantly improve classification accuracy.

Keywords: Sentiment Analysis, Fuzzy Logic, Natural Language Processing, Polarity, Sentiment.

1. Introduction

Sentiment analysis, also known as opinion mining, is a natural language processing (NLP) technique used to determine the sentiment of textual data. Traditional sentiment analysis lexicon-based methods have limitations in handling sarcasm, neutral tones, and context-dependent sentiments. One such tool for sentiment analysis is TextBlob, provides a simple yet effectual way to classify sentiments using polarity and subjectivity scores to classify sentiments into positive, negative, or neutral categories. TextBlob is effective in identifying general sentiments, it struggles with nuances, ambiguity, and borderline cases due to its reliance on static polarity thresholds. To overcome this limitation, we explore the application of fuzzy logic, which allows for handling uncertainty in sentiment classification. This paper presents an approach that integrates fuzzy logic with TextBlob sentiment polarity scores to enhance sentiment classification accuracy. The study aims to analyze the potency of fuzzy logic in sentiment analysis compared to conventional rule-based sentiment classification.

Proceedings DOI: 10.21467/proceedings.7.6; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-989164-9-5

2. Literature Survey

Lexicon-based approaches rely on predefined dictionaries of sentiment-labeled words to determine the sentiment of text. They are easy to implement and do not require labeled training data, making them suitable for quick and domain-specific applications. However, they suffer from key drawbacks. one of the drawbacks is context insensitivity. It means words often change sentiment based on context, which static lexicons can't handle [1]. Negative handling is another drawback in which lexicon methods inadequately handle negations like "not good" [2]. Lexicon method may also suffer with lack of Aaaptability that means static lexicons fail to evolve with language or slang [3]. Fuzzy logic offers a flexible reasoning approach that better models linguistic uncertainties, particularly helpful in handling the ambiguity and vagueness in human sentiments. Vashishtha, Gupta, & Mittal [4] provide a comprehensive review, highlighting how fuzzy systems outperform crisp lexicon-based models in nuanced sentiment detection. Morden, Khuman, & Fasanmade [5] propose a hybrid lexicon-fuzzy system for healthcare-related COVID-19 news, showing superior flexibility over traditional lexicon approaches. Madani, Erritali, & Bengourram [6] combine fuzzy logic with multilingual lexicons using SentiWordNet to enhance cross-language sentiment analysis. Haque [7] introduces a simple but effective fuzzy sentiment classification model that shows robust performance across different domains.

3. Sentiment Analysis and Its Steps

Sentiment analysis generally follows these key steps:

- **Data Collection:** Firstly, textual data is collected from various sources such as social media, reviews, or customer feedback.
- **Preprocessing:** The next stage is cleaning the data by converting text to lowercase, removing stopwords, punctuation, and tokenizing.
- **Sentiment Detection**: Polarity scores (positive, neutral, negative) is assigned to the data.
- **Classification**: classification of sentiment happens using rules or models to determine whether it belongs to positive, negative or neutral class.
- **Visualization and Evaluation**: Finally, the result is presented using confusion matrices, accuracy scores, performance metrics and charts

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4. Fuzzy Logic and Integrated Approach

4.1 Fuzzy logic

Fuzzy logic is a powerful problem-solving methodology. Fuzzy logic, introduced by Zadeh in 1965, is a form of many-valued logic derived from fuzzy set theory. It deals with reasoning that is approximate rather than fixed. Fuzzy provides a method to define conclusions from vague, ambiguous or imprecise information. It has been used in literature with the combination with other techniques to effectively solve a wide range of complex problems [8]. Fuzzy system comprises of four main components: a fuzzification element, an inference system, rules and a defuzzification Fig.1 shows the generalized block diagram of fuzzy system.

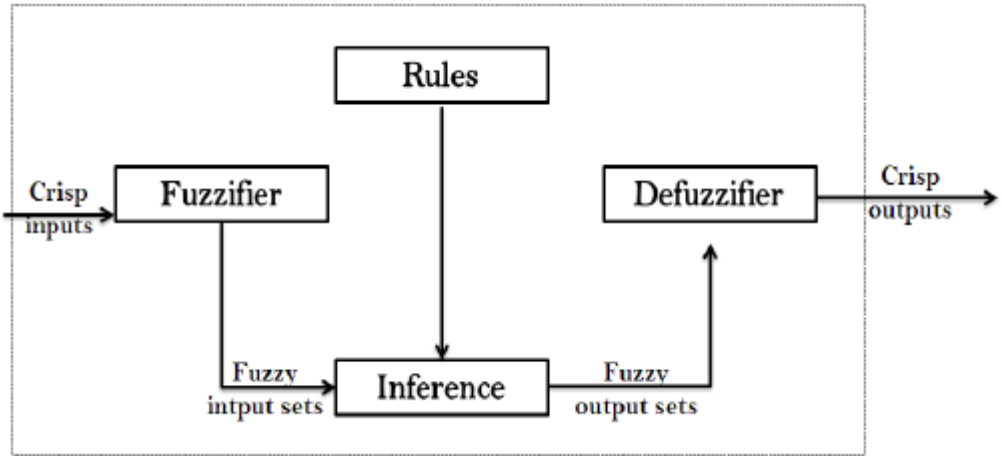

Figure 1: Block Diagram of Fuzzy Logic

The main advantages of fuzzy logic while handling sentiment analysis includes - Handling Ambiguity and Subjectivity, Gradual Sentiment Classification, Improved Handling of Mixed Sentiments, Robustness to Linguistic Variations and Flexibility in Feature Selection.

4.2 Integrated Approach of Fuzzy logic and Text blob -

A fuzzy logic system for sentiment analysis includes four main components. First, Fuzzification transforms input text into fuzzy sets by assigning degrees of sentiment to words. Then, fuzzy rules guide the relationship between inputs and outputs. The inference engine applies these rules to produce fuzzy outputs, which are finally converted into crisp sentiment scores through defuzzification. In sentiment analysis, fuzzy logic allows us to

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create membership functions for sentiment polarity (e.g., negative, neutral, positive) and define inference rules that can better handle ambiguity and linguistic vagueness. By integrating fuzzy inference with sentiment polarity scores (e.g., from TextBlob), we can map crisp polarity values into fuzzy categories and apply reasoning rules to obtain more reliable sentiment decisions. TextBlob sentiment classification polarity score between -1 (negative) and +1 (positive) of a sentence. The polarity score is mapped to sentiment categories using fixed thresholds (e.g., polarity < -0.1 = negative, > 0.1 = positive, otherwise neutral). In the hybrid model (Fuzzy logic + Textblob), polarity score from TextBlob is treated as an input to a fuzzy inference system. Membership functions are defined for polarity (negative, neutral, positive) and output sentiment (negative, neutral, positive). The model starts by using TextBlob to assign polarity scores to preprocessed text. These scores are then input into a fuzzy inference system. The fuzzy model includes:

Input Variable: Polarity (-1 to +1)

Output Variable: Sentiment score (0 to 1)

Apply fuzzy membership functions (triangular membership functions for sentiment classification). Compute fuzzy sentiment scores using the Fuzzy Inference System (FIS).

Fuzzy Rules-

- If polarity is negative, sentiment is negative
- If polarity is neutral, sentiment is neutral
- If polarity is positive, sentiment is positive

Key Components of the Rules

Input (Polarity):

Range: -1 (most negative) to +1 (most positive)

Fuzzy Sets: Negative: Triangular MF between [-1, -1, 0]

Neutral: Triangular MF between [-0.5, 0, 0.5]

Positive: Triangular MF between [0, 1, 1]

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Output (Sentiment):

Range: 0 (negative) to 1 (positive)

Fuzzy Sets:

Negative: Triangular MF between [0, 0, 0.3]

Neutral: Triangular MF between [0.2, 0.5, 0.7]

Positive: Triangular MF between [0.5, 1, 1]

Membership functions -

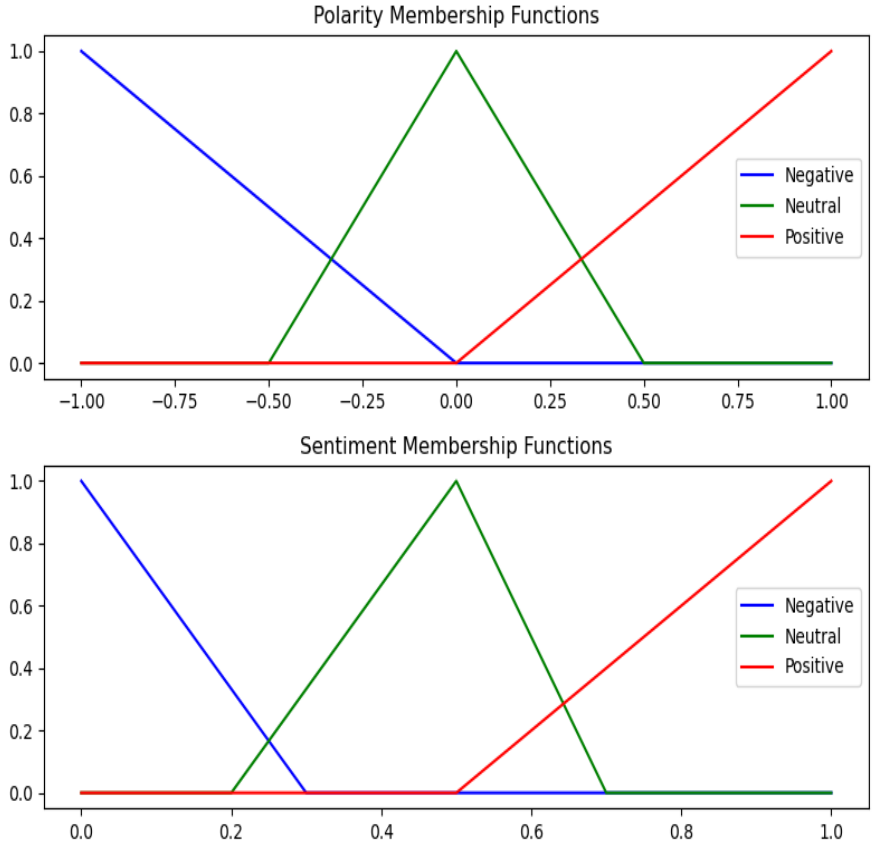

Figure 2: Polarity Membership Functions, Figure 3: Sentiment Membership Functions

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Here is the flow diagram to explain the overall fuzzy sentiment pipeline:

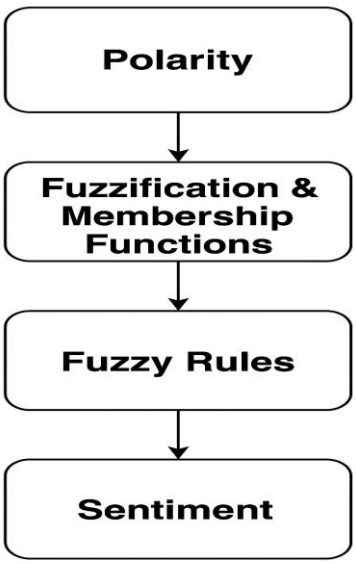

Figure 4: Fuzzy Sentiment Pipeline

Here is the Summary of the Complete Process

Table 1: Process Stages

Stage	**Explanation**
Fuzzification	Convert the crisp TextBlob polarity into fuzzy terms: "negative", "neutral", or "positive" using membership functions.
Fuzzy Inputs	polarity (range: -1 to +1) is the fuzzy input.
Fuzzy Rules	IF-THEN rules determine how polarity maps to sentiment.
Defuzzification	The fuzzy decision is converted back to a crisp number (sentiment score between 0 and 1).
Final Output	The crisp score is classified into final labels: negative, neutral, or positive.

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5. Experimental Results

Experiments were conducted using a dataset containing labeled text with sentiment classes: positive, neutral, and negative. We applied only TextBlob method (python library) and the TextBlob + Fuzzy hybrid approach on the labeled data set. A comparative analysis between traditional sentiment classification (TextBlob) and fuzzy logic-based classification was conducted. The results are presented in the table below:

Table 2: TextBlob Classification Report:

	precision	recall	f1-score	support
negative	0.71	0.34	0.46	134
neutral	0.57	0.63	0.60	200
positive	0.63	0.82	0.71	165
accuracy	0.61	499		
Macro avg	0.64	0.59	0.59	499
Weighted avg	0.63	0.61	0.60	499

Table 3: Fuzzy Logic Classification Report:

	precision	recall	f1-score	support
negative	0.77	0.33	0.46	134
neutral	0.55	0.84	0.66	200
positive	0.75	0.62	0.68	165
accuracy	0.63	499		
Macro avg	0.69	0.60	0.60	499
Weighted avg	0.68	0.63	0.61	499

Accuracy Comparison:

TextBlob Accuracy: 0.61

Text blob + Fuzzy Logic Accuracy: 0.63

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Key Observations:

The fuzzy logic-based approach achieved higher accuracy (63%) than the traditional TextBlob approach (61%). Visualization of the findings has been presented here in form of chart & matrix

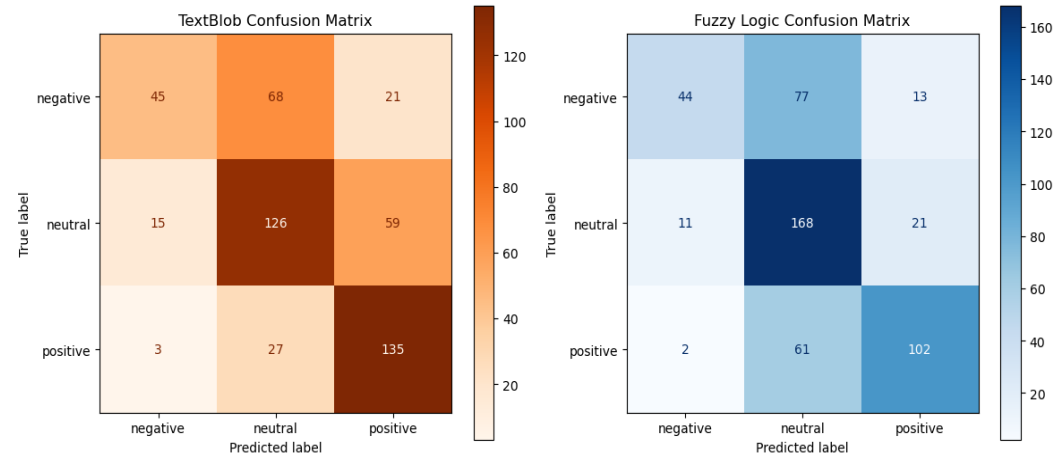

Figure 5: Confusion Matrix

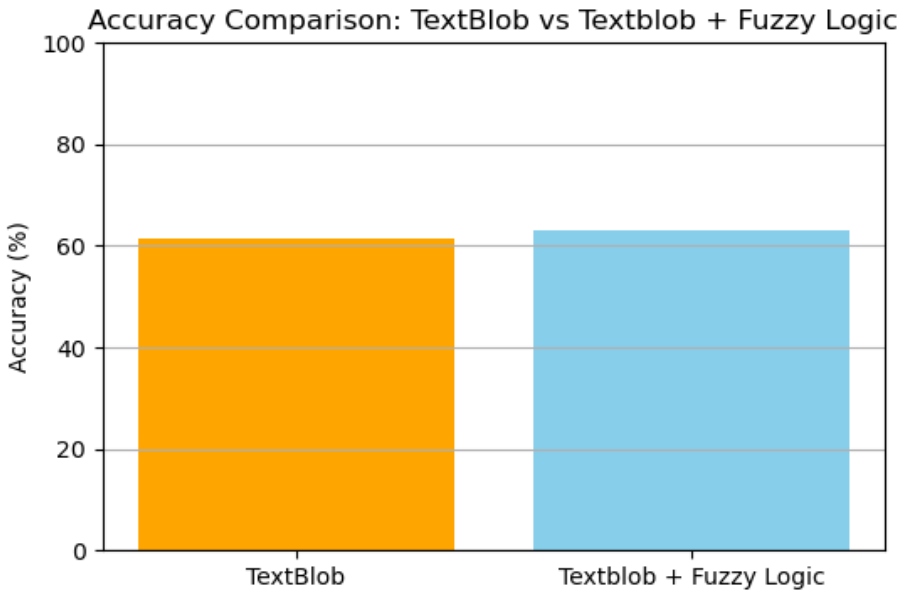

Figure 6: Accuracy Comparison

6. Conclusion

Sentiment analysis involves determining the emotional tone behind a body of text. SA is a key natural language processing (NLP) technique aimed at identifying and categorizing emotions in textual data. The study presented in this paper demonstrates that while TextBlob

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offers a lightweight solution for sentiment analysis, its performance is limited by static thresholds. By integrating fuzzy logic into the sentiment mapping process, we can account for the uncertainty and gradations in human language more effectively. The experimental results support that the fuzzy-enhanced model offers better accuracy. Future work may explore combining this method with advanced embedding techniques or expanding the fuzzy rule base.

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