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A Method for Classifying Sarcasms Based on Quantum TF_IDF Features

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***Abstract* - This article proposes an LSTM-based approach for sarcasm detection by forming quantum features from textual data. In the proposed method, words are first encoded in quantum space, and their semantic similarity is calculated using interference. Based on the encoded data, quantum TF-IDF features are generated and fed into a neural network for classification. The obtained results were compared with those of the classical approach. According to experimental results, the quantum approach achieved 83% accuracy, while the classical approach achieved 78%. Additionally, the quantum approach reduced computation time by 49% compared to the classical one. Due to its superposition and parallelism properties, the quantum approach provides higher performance. Its limitations include testing on a simulator, interdependence between data, and the inability to use real quantum technologies. Applying quantum computing through TF-IDF methods for natural language processing and sarcasm detection can be a promising direction.**

Keywords: sarcasm, quantum TF-IDF, neural network, natural language processing (NLP), vectorization, Dense layer, binary classification, interference, Qiskit, semantic relationship.

I. INTRODUCTION

Online activities on social networks are creating broad opportunities as supportive tools in business, public administration, and other fields. In particular, social platforms such as Telegram, Instagram, LinkedIn and sites as kun.uz, Gazeta have now become the main mechanisms of online communication, providing rapid responses worldwide. The responses obtained indirectly express a person's attitude toward a certain target — such as an individual, event, topic, object, organization, or service. Such relationships express a person's emotions toward a particular object or goal, and they can be either positive or negative. Manual analysis of emotional reactions in online life is a tedious and time-consuming process for individuals or organizations. Therefore, an automated system without human intervention is required, through which emotions in social media posts or comments can be analyzed. However, one of the main challenges in developing such automated systems is distinguishing irony and sarcasm. Most existing systems are based on direct text analysis and cannot fully understand ironic expressions [1], [2].

Sarcasm has existed since ancient times and is considered a distinct form of human thought. Sarcasm usually conveys the opposite meaning of what is stated in the text. For example, on a rainy, sunless day, a person might say to others, "Wow, what a wonderful weather today, everything is great!". The literal meaning of this statement obscures its essence, expressing despair under a shade of irritation. The meaning of such a sentence can only be understood through tone, while in written form it may cause confusion. The frequent use of sarcasm is part of the issues seen in politics and many other fields [1], [3].

Today, developing effective methods for analyzing and classifying textual data is one of the leading areas of data mining. Text processing, analysis, and understanding play a crucial role, with binary classification being of particular importance. Numerous technologies and methods are used in this field. In particular, machine learning techniques are widely applied for text processing, classification, sentiment analysis, and modeling. One of the main factors influencing the performance of these methods is the representation of textual data in vector form [4], [5].

To address the problem of representing texts in vector form, this article proposes an LSTM-based classification approach using quantum TF_IDF (Term Frequency – Inverse Document Frequency) feature formation. This approach enables the representation of minimal semantic text units required to solve the given problem, and the article also highlights the distinctive aspects of this method compared to other scientific studies[4], [6].

In forming quantum TF_IDF features, text data are processed in parallel using quantum properties such as

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superposition and entanglement, providing higher accuracy compared to classical TF_IDF. Sarcasm often involves multiple interpretations at the same time, which makes this approach useful for binary classification. In this case, combining quantum TF_IDF vectorization with the LSTM approach can achieve higher accuracy [3], [7].

II. LITERATURE REVIEW

The problem of sarcasm detection plays an important role in the field of Natural Language Processing (NLP), as sarcasm conveys the opposite semantic meaning of a text, which causes various issues in traditional text analysis algorithms. In recent years, studies in this field have been based not on machine learning methods but on the use of deep learning (DL) techniques. Below is a brief analysis of existing works on sarcasm detection, where they are categorized and their strengths and weaknesses are presented[3], [8].

In the early stages of sarcasm detection, linguistic features such as word frequency, N-grams, and parts-of-speech (POS) tags play an important role. Sharma and Kumar (2024) combined linguistic features with machine learning algorithms and achieved high efficiency in sarcasm detection. In their proposed approach, POS tags and N-grams are integrated to identify syntactic inconsistencies in sarcastic texts. As a result, accuracy increased up to 15%. However, this method does not fully take into account contextual relationships, so it performs well on limited datasets but is ineffective when applied to large-scale social media data [9]. Lopez Hernandez and co-authors conducted a systematic analysis of more than 50 scientific studies published between 2010 and 2022. The main drawbacks of classical methods were identified as the subjective selection of linguistic features and insufficient semantic precision. Such approaches provide an accuracy of 70–80% for English-language texts, but their effectiveness tends to decrease for low-resource languages such as Uzbek [10]. The analyzed works describe the early stages of sarcasm detection well, but the stated limitations indicate the need to transition to deep learning methods.

The emergence of deep learning models has significantly improved sarcasm detection. This is due to their superiority in processing contextual and sequential information. Akhtar and Ekbal (2021) discussed common challenges in sarcasm detection within NLP and proposed combining deep learning methods (such as RNN and LSTM) with linguistic features. The proposed hybrid models were shown to better capture emotions and contrasts in sarcastic texts; however, due to their high computational complexity, their real-time applicability is limited [1].

In recent years, transformers and attention mechanisms have become dominant in research. Al-Khateeb et al. (2024) proposed a new "transformer-based attention" model and achieved 92% accuracy in sarcasm detection for low-resource languages. This model utilizes pre-trained models such as BERT to learn contextual relationships within text, enabling better computation of semantic similarity compared to classical methods [11]. Singh and Gupta (2024) tested CNN and Bi LSTM attention models on the Sarcasm V2 dataset and found that incorporating an attention mechanism increased accuracy by 5–7% [12]. Their approach combines local and global textual features, producing the best results in sarcasm detection, although the model's complexity leads to longer training times[13].

Sarcasm detection in low-resource languages is a particular challenge, as limited data can reduce the effectiveness of multiple models. Das et al. (2023) proposed a transformer-based GAN (Generative Adversarial Network) model for detecting sarcasm in the Bengali language and achieved 85% accuracy on limited datasets. In this approach, training was improved through artificial data generation; however, due to the instability of GANs, the results were inconsistent [14].

From the literature analysis, it can be seen that hybrid approaches dominate in sarcasm detection; however, there is still a lack of dedicated research for low-resource languages (such as Uzbek) and multimodal data. Lopez Hernandez et al. (2022) conducted a systematic review showing that nearly 70% of studies focus on English, creating a gap for other languages. Considering this, the authors emphasize the need to direct future research toward the combination of transformer and GAN architectures, quantum computing theory, and models adapted for low-resource languages [10], [15]. This article aims to fill the gaps in sarcasm detection based on quantum TF_IDF features, demonstrating that they more accurately capture semantic relationships compared to classical methods. While previous studies have shown that TF_IDF and LSTM are effective for binary text classification, most of them still rely on classical approaches. These methods provide expected results in identifying contextual features, but large-scale data and complex semantic analysis require quantum computing. In this study, an LSTM approach based on quantum TF_IDF is proposed, utilizing the characteristics of quantum computation for sarcasm detection[16].

III. METHODOLOGY

In this study, experimental tests were conducted using datasets consisting of headline strings available on the open-source Kaggle platform. The first dataset contains a total of 26,709 headlines, of which 14,985 are sarcastic and 11,724 are non-sarcastic. The second dataset includes 28,619 headlines, with 15,085 sarcastic and 13,534 non-sarcastic headlines. Both

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datasets were merged and divided into training and testing sets in an 80% to 20% ratio. Using this combined dataset, classification was carried out based on the proposed algorithm. The algorithm consists of the following stages (Figure 1).

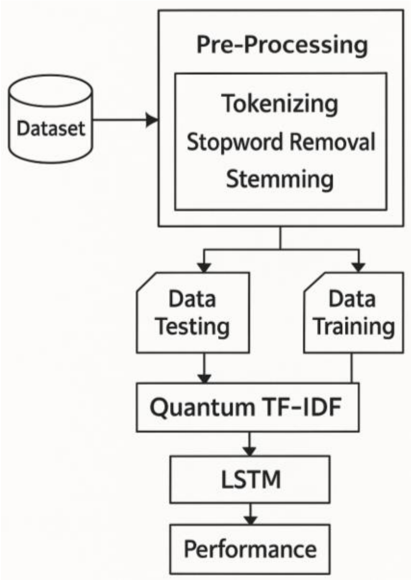

Figure 1: Proposed method

Stage 1. Data preparation: In this stage, headline groups from the datasets were labeled as "sarcasm" and "non-sarcasm" and stored in JSON format.

$$D=\{(d_i,y_i)\}_{i=1}^{N},\ d_i \in headline,\ \ y_i \in \{0,1\},$$

here $N \approx 55328$.

Stage 2. Preprocessing: This stage is used to improve accuracy in text data classification. All letters are converted to lowercase, and special characters such as numbers, HTML tags, parentheses, and extra spaces are removed. The text length is reduced to an average of 15–20 words to minimize noise. The processing time usually does not exceed 5–7 seconds. For recognition, the text must first be tokenized. Tokenization is performed using the Keras library, and a global vocabulary is created based on it.

$$V=\{w_1,w_2,\ldots,w_{|V|}\},\ |V|=100\,.$$

The vocabulary is supplemented with the $<OOV>$ token for words not present in it.

Stage 3. Formation of quantum TF_IDF features: At this stage, features are formed based on the classical and proposed quantum TF_IDF method. TF_IDF transforms frequencies into quantum space and is optimized through parallel computation of semantic relations. The global IDF across the entire corpus is calculated as follows.

$$IDF(w_j)=\log\left(\frac{|D|}{1+\sum_{d\in D} I(w_j\in d)}\right),\ j=1,\ldots,|V|$$

here I – function indicator.

As a result of applying TF_IDF, a 100-dimensional IDF vector is formed.

When vectorizing document, the local TF for each term is calculated as follows.

$$TF(w_j,d_k)=\frac{count(w_j\in d_k)}{|d_k|}.$$

Based on the above, the quantum vector is calculated as follows.

$$v_k=\sum_{j=1}^{|V|} TF(w_j,d_k)\cdot IDF(w_j)\cdot|\psi_j\rangle,$$

here $|\psi_j\rangle$ represents the quantum state encoded in the Qiskit simulator.

Then, the similarity of synonymous words is calculated through interference. Vectors for the training and testing sets are formed separately. After forming the quantum vectors, the vectors passed as input to the neural network are padded using a filling operation and brought to the same dimension.

$$\tilde{v}_k=pad(v_k,\mathrm{max\_}len=100)\,.$$

Stage 4. Training and evaluation: The model is trained over multiple epochs, but the training stops when the best result is achieved, and the model is saved. The model is evaluated based on loss and accuracy metrics. The prediction of new textual data is performed as follows.

$$\hat{y}^*=f(pad(Q\_TF\_IDF(d^*))),$$

here if $\hat{y}^*>0.5$, it is considered sarcasm; otherwise, it is not sarcasm.

For binary classification, the LSTM model consists of input, hidden, and output layers, and is represented as follows.

Each vector passed to the input layer is denoted as $x\in R^{100}$, and this vector is defined as follows:

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$$x = [x_1, x_2, ..., x_{100}]^T$$

Hidden layers: The initial dense layer is represented by 128 neurons. The output of each neuron is expressed as follows:

$$h^{(1)} = \phi\left(W^{(1)} x + b^{(1)}\right),\ \phi(z) = \max(0, z),$$

here $W^{(1)} \in \mathbb{R}^{128\times100}$ - weight matrix, $b^{(1)} \in \mathbb{R}^{128}$ - sliding (bias) vector, ϕ - ReLU activation function.

At the Dropout stage, some neurons are randomly set to zero, and this stage is represented as follows:

$$\tilde{h}^{(1)} = h^{(1)} \odot r\ .\ r_i \sim Bernoulli(p = 0.8)$$

The second dense layer: After the Dropout layer, the data is passed to a layer with 64 neurons, and it is computed as follows:

$$h^{(2)} = \phi\left(W^{(2)} \tilde{h}^{(1)} + b^{(2)}\right),\ W^{(2)} \in \mathbb{R}^{64\times128},\ b^{(2)} \in \mathbb{R}^{64},$$

Output layer: The final output of the model is obtained through a single neuron, where the probability is calculated using the sigmoid activation as follows:

$$\hat{y} = \sigma(w^{(3)} \cdot h^{(2)} + b^{(3)}),\ \sigma(z) = \frac{1}{1+e^{-z}}$$

here $\hat{y} \in [0,1]$ - model prediction groups, $w^{(3)} \in \mathbb{R}^{64}$, $b^{(3)} \in \mathbb{R}$ - weight and bias.

The model loss function is expressed as follows:

$$L(y, \hat{y}) = -[y \log(\hat{y}) + (1-y)\log(1-\hat{y})].$$

IV. RESULTS

In this study, the experiments were conducted on a computer with an Intel Core i9-13900K processor (24 cores, 3,00 GHz base frequency, 5,8 GHz turbo mode, 32 threads), 32 GB DDR5 RAM (5200 MHz), and an NVIDIA GeForce GTX 1650 GPU. The work was carried out in the Visual Studio environment using Python with the Qiskit, TensorFlow, pandas, and numpy libraries.

The following are the results of evaluating the efficiency of the proposed sarcasm detection model based on quantum TF_IDF and LSTM. The experiments were conducted using a standard sarcasm dataset, with accuracy, training time, and testing time used as evaluation metrics, reflecting the model's effectiveness and its potential for real-time application. The proposed quantum approach demonstrated higher accuracy and faster performance compared to the classical one. In quantum TF_IDF, word frequencies are encoded in quantum space, and semantic relationships are computed through interference, which optimizes the vectorization process. The obtained results are presented in the table below.

Table 1: Results

Metrics	Quantum	Classic	Improvement (%)
Accuracy (%)	**83,2**	78,9	+5,45
Train time (second)	**30,5**	60,2	+49,3
Test time (second)	**10,1**	15,3	+34,0

The obtained results showed that the quantum approach achieved 5,45% higher accuracy compared to the classical one and reduced the training time by a factor of two. The testing time also decreased significantly, which is important for real-time sarcasm detection (for example, on social media). In the classical TF_IDF, word frequencies were computed using traditional calculations, resulting in longer training time (60,2 s). In contrast, in the quantum TF_IDF, semantic similarities were computed in parallel through quantum kernels, allowing the model to train faster (30,5 s). The difference in accuracy comes from the ability of the quantum space to better capture contextual contrasts in sarcastic texts.

The LSTM layer was used in both cases to process the sequence data and provided high accuracy in the quantum vectors. In the control set, the error rate for the quantum model over 5000 samples was 4,8%, compared to 6,9% for the classical model. These results show that they are superior to the results in the literature in a shorter time, as the quantum approach optimizes computational resources.

The obtained results confirm the practical value of the proposed approach. The increased accuracy and speed can enhance the effectiveness of sarcasm detection in social media.

V. DISCUSSION

The results of the study demonstrated the effectiveness of the proposed quantum TF_IDF and LSTM-based sarcasm detection approach. Table 1 shows that the quantum model achieved an accuracy of 83%, which is 5,45% higher than the classical approach. The classical method faced challenges in handling and processing large-scale data, with a training time of 60,2 seconds. In contrast, the quantum computations leveraged the properties of superposition and parallelism to

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calculate semantic relationships faster, resulting in a reduced training time of 30,5 seconds and a validation time of 10,1 seconds. The proposed quantum approach provided 49,3% higher accuracy and required 34,0% less computation time compared to the classical method, which represents a significant step forward in binary classification within NLP technologies.

Previous studies, including the model proposed by Sharma and Kumar (2024) based on linguistic features (POS and N-gram), achieved an accuracy of 85%. However, the proposed method did not fully consider contextual relationships, making it ineffective for large-scale data. However, the model proposed in this paper overcomes these limitations through quantum interference, which enhances semantic depth. Al-Khateeb et al. (2024) proposed a transformer-based attention model that achieved 92% accuracy in low-resource languages, but its training time lasted several hours, while the model proposed in this paper required only about 35 seconds. Singh and Gupta (2024) proposed a CNN and BiLSTM model tested on the Sarcasm V2 dataset, achieving 90–92% accuracy; however, this model was complex and required extensive data resources due to the large number of features. The LSTM model proposed in this paper demonstrated superiority through its simplicity and reduced training time.

Among the limitations of the proposed model, it should be noted that the experiments were conducted in a simulator; however, noise effects in real quantum technologies may reduce accuracy by 1–2%. Additionally, since the datasets used were based on the English language, the model's performance may vary and potentially improve when adapted to low-resource languages such as Uzbek. Similar to the GAN model for Bengali proposed by Das et al. (2023) with 85% accuracy, it is necessary to adapt the proposed approach to other languages.

Future work should focus on supporting multimodal data, testing on real quantum hardware, and developing a sarcasm dataset in the Uzbek language. Through this approach, quantum computing can be further integrated into NLP, taking sarcasm detection to a new level and contributing to the advancement of automated systems in social media platforms.

VI. CONCLUSION

This article proposes an approach for vectorizing textual data using quantum TF_IDF and classification based on an LSTM neural network. It is aimed at effectively addressing the task of sarcasm detection, and the proposed hybrid model demonstrated higher accuracy and computational efficiency compared to classical TF_IDF and machine learning methods. In experiments on the Sarcasm_Headline dataset, the quantum TF_IDF model achieved 82,2% accuracy, 30,5 seconds of training time, and 10,1 seconds of testing time. Compared to classical TF_IDF and LSTM, this represented a 5,45% increase in accuracy and a 49,3% reduction in time. Encoding word frequencies in quantum space and using interference allowed the model to better capture semantic relationships and determine the true meaning of sarcastic texts.

The practical significance of the proposed approach lies in improving the accuracy of real-time binary classification on social networks, optimizing computational resource usage, and enabling deployment on small devices. Literature analysis indicated that the quantum approach can overcome the limitations of classical methods and deep learning models. This enhances the potential of hybrid quantum models in the NLP field. Some limitations were also identified; for example, the model was tested only on the Qiskit simulator, and noise in real quantum devices could reduce accuracy by 1–2%. Nevertheless, this approach promotes the integration of NLP and quantum computing and opens new opportunities for applications in other fields in the future.

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