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Enhancing Support Vector Machine Performance Using Particle Swarm Optimization for Arabic Text Classification

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Abstract:

Arabic is a highly complex language due to its rich morphology, linguistic diversity, and the limited availability of high-quality labeled datasets. In this paper, we address these challenges by proposing a hybrid model that combines Support Vector Machines (SVM) with Particle Swarm Optimization (PSO) to improve Arabic text classification performance. Although SVM has demonstrated strong effectiveness in classification tasks, its performance largely depends on the appropriate tuning of its hyperparameters. Therefore, PSO is employed as a metaheuristic optimization technique to automatically optimize key SVM parameters, including the penalty parameter (C), Gamma, kernel type, and feature subset selection. The proposed SVM-PSO model was evaluated using an Arabic corpus collected from various online sources covering multiple domains, including news (sports and politics), history, geography, and information technology. Experimental results demonstrate that the proposed approach significantly outperforms several traditional machine learning classifiers. The model achieved a classification accuracy of 99.2%, with precision of 99.1%, recall of 99.0%, and F-score of 99.1%. In comparison, standard SVM achieved an accuracy of 92%, Naive Bayes 88%, and Random Forest 94%. These results indicate that integrating metaheuristic optimization with classical machine learning techniques can produce a robust and effective classifier for Arabic text processing tasks within the field of Natural Language Processing.

Keywords: Arabic Text Classification, Support Vector Machine (SVM), Particle Swarm Optimization (PSO), Natural Language Processing (NLP), Hyperparameters Optimization.

1. Introduction

Arabic is one of the most spoken languages in this world, with a complex morphological structure leading to the richness and diversity that make NLP tasks such as text classification very challenging [1]. Text classification is the problem of assigning pre-defined categories to text

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documents and it is a basic task in several applications such as sentiment analysis [2], spam detection, news categorization and also information retrieval. Arabic has unique properties, in terms of derivational morphology, diacritics and lack of capitalization that need to be taken into account when processing it effectively [3].

Although it is a model that has been shown to be highly effective in a wide variety of text classification problems due to its strong theoretical basis and high-dimensional data handling capability (4), SVM's performance depends on choosing factors appropriately. Other factors can lead to sub-optimal hyperparameter settings and thus less than optimal accuracy and generalization abilities [5].

PSO is a population based metaheuristic optimization method, inspired by bird or fish swarm [6]. It has been applied to a variety refinement problems/tasks including feature selection [7] and hyperparameter optimization in machine learning, and shown experimental success. Its ability to learn complex search spaces automatically makes it potentially a good candidate for optimizing SVM parameters.

In this paper, a new method to improve Arabic text classification using SVM and PSO combination has been introduced. The main aim is to exploit PSO for joint optimization of SVM hyperparameters and feature selection manipulations leading to an enhanced classification accuracy on the multi-domain dataset from Arabic. The purpose of this proposed work is to overcome the shortcomings of conventional SVMs in dealing with complexities and intricacies present in Arabic text, and hence proposing a more robust as well as accurate classification model.

The rest of this paper is organized as follows: Section 2 reviews the Literature Review on Arabic text classification, SVM, and PSO. The details of the SVM-PSO approach are provided in Section 3. Experimental settings and results are presented in Section 4. Concluding remarks and future research prospects are given in Section 5.

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2. Literature Review

This section provides a summary of previous studies and survey articles related to data augmentation and text classification. It highlights the main approaches, methods, and models used in both Arabic and other languages, discussing traditional machine learning techniques, deep learning methods, hybrid models, and optimization strategies. The review identifies gaps in the current research and sets the context for the proposed study.

Abdhood et al. conducted a comprehensive review of data augmentation techniques for Arabic text classification. The authors analyzed numerous studies that applied traditional machine learning algorithms such as Naïve Bayes (NB), k-Nearest Neighbors (KNN), and Support Vector Machines (SVM) for evaluating classification performance on augmented Arabic text datasets. Their analysis showed that these conventional classifiers are still widely used as baseline models in Arabic Natural Language Processing tasks and can achieve competitive performance when combined with appropriate feature representation techniques [8].

Ahmed et al. proposed and evaluated a feature-based approach for classifying three Arabic text types (prose, classical Arabic poetry, and Al-Hur poetry). They preprocessed a self-collected dataset (tokenization, removal of non-Arabic characters/stopwords, and conversion to Boolean feature vectors) and used TF-IDF–style feature extraction to convert texts into numerical representations. The authors trained and compared three classical classifiers—Support Vector Machine (SVM), Linear Support Vector Classification (Linear SVC), and Naïve Bayes (NB)—as supervised baselines. Their results showed that Linear SVC achieved the best overall performance (average precision ≈ 0.753, recall ≈ 0.623, F-measure ≈ 0.673), Naïve Bayes performed competitively on some classes with higher recall (average precision ≈ 0.687, recall ≈ 0.723, F-measure ≈ 0.593), while SVM produced the lowest averages (precision ≈ 0.407, recall ≈ 0.317, F-measure ≈ 0.357). The authors conclude that preprocessing choices and dataset size strongly

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affect outcomes and that Linear SVC served as the most effective baseline for their Arabic text classification task. [9].

Alhaj et al. observed that, although deep learning models have demonstrated strong performance on text classification tasks, they typically require very large amounts of labeled data and substantial computational resources for training and inference. The authors based this observation on the high number of model parameters, the risk of overfitting when data are scarce, and the complexity of modern neural architectures that increase training time and memory/compute demands. They conclude that these limitations are especially problematic for low-resource languages (such as Arabic) and recommend considering alternative or mitigating strategies — for example, careful feature selection, dimensionality reduction, transfer learning, and data augmentation — to achieve effective performance without prohibitive computational costs [10].

Much of the previous work has focused on improving the performance of machine learning algorithms when it comes to Arabic text. Alayba and Altamimi proposed an Arabic text classification approach that combines word embeddings with Support Vector Machines (SVM). The model was evaluated on a dataset containing 12,000 Arabic documents across multiple categories and achieved an accuracy of 95.4% [11]. In a similar study, Tiwari et al. proposed a hybrid PSO-EFVM model that integrates Particle Swarm Optimization (PSO) with four ensemble learning techniques (Adaptive-Boost, Gradient-Boost, Random-Forest, and Extremely-Randomized Tree) to enhance sentence-level sentiment analysis. Their most significant results showed superior performance over traditional models and advanced ones like BERT and XLNet, achieving an average test accuracy of 89.54%, weighted F1-score of 88.6%, and ROC-AUC of 88.6% across five diverse cross-domain datasets (Sentiment-140, Reddit-App, Amazon-Shopping, Alexa-Product, and SMS-Collection Reviews) [12].

Hijazi, Zeki and Ismail. proposed a two-stage hybrid feature-selection method for Arabic text classification that combines the chi-square filter with a binary Artificial Bee Colony (ABC)

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wrapper to reduce dimensionality and improve classification performance. First, they apply chi-square to quickly eliminate many irrelevant features (reducing the original 82,103 features to 2,444). Then they run a binary ABC search over the reduced set to find compact feature subsets that maximize classifier accuracy, using a forward search strategy and bit-vector food-sources where Naive Bayes accuracy is the fitness function. Key ABC settings included 200 food sources, MAXLIMIT = 10, MR = 0.1, and 200 iterations; during neighbor exploration they restrict modifications to 7–50 features per step to avoid large jumps. They evaluate on the BBC Arabic dataset (4,222 documents across seven categories) with UTF-8 preprocessing, stopword removal, Boolean bag-of-words representation (no stemming), and 10-fold cross-validation. Classifiers used for assessment were Naive Bayes, SVM, and J48 (Weka implementations), and weighted F1-measure was reported. Results show the hybrid CHI-ABC method selected only 1,812 features and achieved better weighted F1 (e.g., NB: 77.72) than using chi-square or ABC alone, demonstrating improved accuracy and reduced computation compared with ABC-only selection [13].

Fouad et al. evaluated Arabic fake-news detection using only textual features on three datasets (a real social-media set of 1,980 items, a benchmark of 2,578, and a merged set of 4,561), applying standard preprocessing (cleaning, tokenization, stop-word removal, stemming, padding) with Keras word embeddings, comparing several machine-learning classifiers (LinearSVC, SVC, Multinomial/Bernoulli NB, SGD, Decision Tree, Random Forest, K-NN with n-grams) and deep models (CNN, LSTM, BiLSTM, CNN+LSTM, CNN+BiLSTM; CNN: 64 filters, LSTM: 128 units; Adam lr=0.01, weight decay 0.0005, batch size 128, dropout 0.5), evaluated with 80/20 splits and 5-fold cross-validation using accuracy, loss and AUC (and F1 for ML); they found BiLSTM (and BiLSTM+CNN) consistently achieved the best performance (e.g., Dataset1 accuracy ≈ 84.8%, AUC ≈ 0.903; 5-fold BiLSTM ≈ 83.9% accuracy, loss 0.86) while plain CNN performed worst, concluding that text-only BiLSTM models are effective for

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Arabic fake-news detection and recommending future work on hybrid architectures and pre-trained embeddings [14].

However, a significant research gap exists in the comprehensive application of PSO for simultaneous hyperparameter optimization and feature selection within an SVM framework specifically tailored for diverse multi-domain Arabic text classification. Many studies either focus on specific domains, use standard SVM without extensive optimization, or primarily leverage deep learning, which can be computationally intensive. This paper aims to bridge this gap by presenting a robust and efficient SVM-PSO model that achieves high accuracy with optimized parameters and features.

3. Proposed SVM-PSO Methodology

This section presents the proposed hybrid SVM–PSO methodology for Arabic text classification. As illustrated in Figure 1, the overall system architecture consists of a sequence of interconnected stages designed to enhance classification performance. The process begins with comprehensive data preprocessing, followed by text normalization and tokenization, stop-word removal, and stemming. Subsequently, relevant textual features are extracted using the TF–IDF scheme.

Then, PSO is applied as an optimization technique in order to perform simultaneously feature selection and SVM hyperparameters tuning (such as the regularization parameter (C), type of kernel and kernel specific parameters, for example gamma). The trained SVM classifier is then retrained by the optimized feature set and hyperparameters for the classification. Performance is measured based on the standard collection of characteristics including both accuracy and F1-score as presented in Figure. 1.

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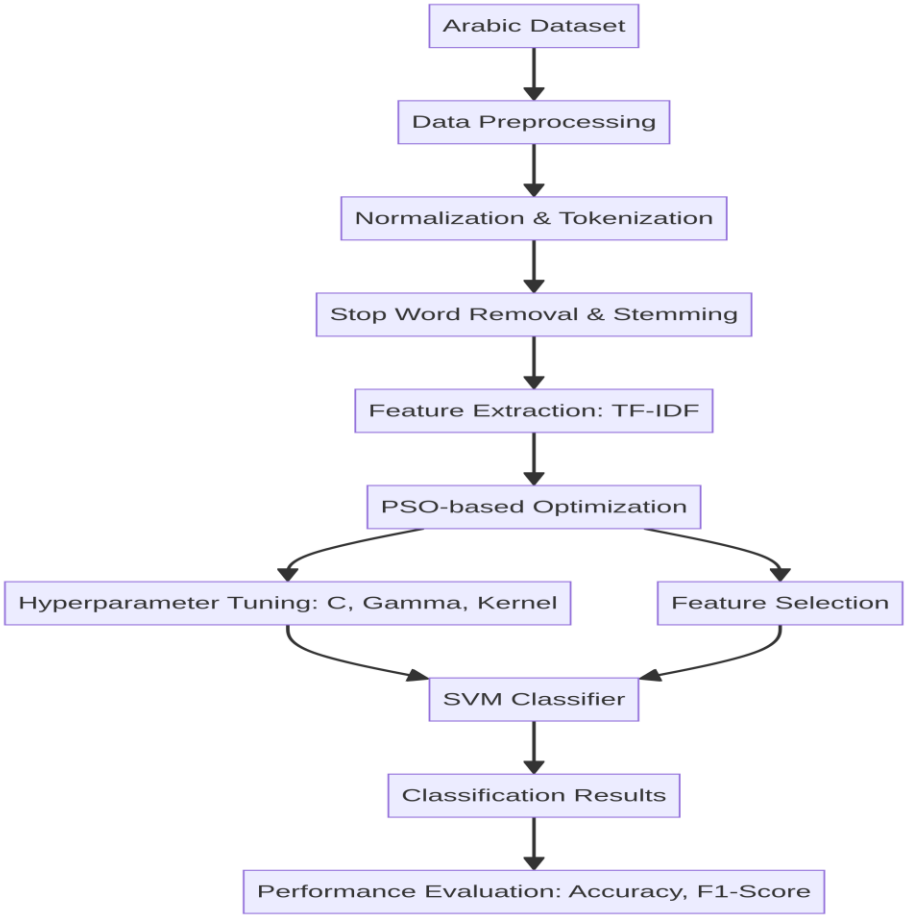

Figure 1: The proposed hybrid SVM–PSO methodology

3.1. Dataset Description

The dataset used in this study consists of a corpus of Arabic news articles collected from several publicly accessible Arabic online news portals and digital media platforms. The objective of compiling this dataset was to construct a multi-domain Arabic text corpus suitable for evaluating the performance of machine learning models in Arabic text classification tasks.

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The dataset contains a total of 5,000 Arabic news articles, which are evenly distributed across five thematic categories: Sports, Politics, History, Geography, and Information Technology (IT). To ensure a balanced experimental setting and avoid bias toward a specific category, each category contains 1,000 documents.

The articles were collected from well-known Arabic online news websites and educational content platforms that provide publicly available textual content. Specifically, the articles were crawled from prominent portals such as Al-Jazeera, Al-Arabiya, and BBC Arabic, ensuring a diverse representation of Modern Standard Arabic (MSA) across different domains. The data collection process was conducted during the period from January 2023 to September 2024, ensuring that the corpus reflects relatively recent textual material while covering diverse topical domains.

From a linguistic perspective, the dataset primarily consists of Modern Standard Arabic (MSA), which is the formal variety commonly used in news reporting, official publications, and academic writing across the Arab world. Due to the formal nature of the selected sources, the presence of Dialectal Arabic (DA) expressions is minimal and does not constitute a significant portion of the dataset. Table 1 summarizes the distribution of documents across the five categories.

Table 1: shows the number of documents in each category

Category	Number of Articles
Sports	1000
Politics	1000
History	1000
Geography	1000
Information Technology	1000
Total	**5000**

3.2. Data Preprocessing

Arabic text is a complex language structure, in which it demands careful and sophisticated pre-processing. The preprocessing steps are: (1) normalization: standardizing characters i.e replacing

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(‘آ‘ ,’إ‘ ,’أ‘) with a character (‘ا’). (2) Tokenization: Splitting text into words or tokens. (3) Stop Word Removal: removal of the common Arabic stop words that do not provide useful information regarding the classification (e.g. ‘على‘,’في‘ ,’من‘). (4) Stemming/Lemmatization: Transforming words into base form takes out some variability and reduces dimensions. In case of Arabic, light stemming or root extraction methods are preferred because it is highly morphology rich.

3.3. Feature Extraction

After preprocessing, text documents are transformed into numerical feature vectors. The Term Frequency-Inverse Document Frequency (TF-IDF) technique was employed for feature extraction. TF-IDF assigns weights to terms based on their frequency within a document and their rarity across the entire corpus, effectively capturing the importance of words in distinguishing between categories.

3.4. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is utilized to optimize two critical aspects of the SVM classifier: hyperparameter tuning and feature selection. Each particle in the swarm represents a potential solution, encoded as a vector containing both SVM hyperparameters (C, Gamma, Kernel type) and a binary mask for feature selection.

- **PSO for Hyperparameter Tuning**

The SVM hyperparameters optimized by PSO are: (1) C (Regularization Parameter) - It controls the trade-off between increasing the margin size and keeping misclassification low. (2) Gamma (Kernel Coefficient): This parameter defines the influence of a particular training example and is important for RBF, Polynomial, and Sigmoid kernels. (3) Kernel Type: This is the function used to map input data into higher dimension of space, e.g., Linear, RBF or Polynomial kernel.

- **PSO for Feature Selection**

In addition to hyperparameter tuning, PSO is also used to select the most relevant features from the TF-IDF vector space. Each particle’s position includes a binary vector where ‘1’ indicates the

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selection of a feature and '0' indicates its exclusion. This simultaneous optimization helps in reducing dimensionality, mitigating overfitting, and improving computational efficiency.

- **Fitness Function**

The search for the best solution is based on fitness function in PSO algorithm. In this study, the fitness function is set to be classification accuracy of SVM model on validation dataset. It repeatedly modifies the position and velocity of particles to minimize fitness function.

3.5. Support Vector Machine (SVM) Classification

After identifying the best hyperparameters and feature subset selected by PSO, the SVM classifier could be trained with these tuned parameters. The SVM searches for the optimal hyperplane to maintain the maximum separation margin between support vectors of different classes in feature space).

4. Experimental Setup

This section summarizes the experimental setup used to evaluate the proposed SVM–PSO model for Arabic text classification, including datasets, preprocessing, feature representation, and parameter settings for SVM and PSO. It also presents the results analyzed with standard performance metrics, allowing a clear comparison with baseline methods. The findings demonstrate the model's robustness, efficiency, and superior classification performance across various conditions.

4.1. Experimental Setup

The experimental evaluation was conducted using the Python programming environment, where the Support Vector Machine (SVM) classifier was implemented utilizing the scikit-learn library due to its robustness and widespread adoption in machine learning research. Particle Swarm

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Optimization (PSO) was implemented as a custom optimization module to enable flexible control over feature selection and hyperparameter tuning processes.

The dataset was randomly split into three sets (train, validate, and test) to achieve an unbiased and dependable evaluation: 70% of the data were used for training model development, 15% were employed to determine set-up parameters, and the last 15% for independent testing. Such a data-splitting scheme was implemented to avoid over-fitting and ensure a reasonable generalization evaluation for the proposed model.

To quantitatively assess the classification performance, multiple standard evaluation metrics were employed, including accuracy, precision, recall, and F1-score. These metrics provide a comprehensive evaluation by capturing both overall classification correctness and class-specific predictive performance.

4.2. Performance Metrics

- **Accuracy**: The percentage of right classified instances over the total instances.
- **Precision**: The percentage of correct predictions amongst all observations.
- **Recall**: The fraction of the true positive predictions out of all the predictive positive cases.
- **F1-Score**: Harmonic mean of precision and recall, measures for the performance tradeoff.

5. Results and Discussion

The proposed SVM-PSO model achieved exceptional performance in Arabic text classification, outperforming traditional methods. Standard SVM showed moderate accuracy, while Random Forest performed better but remained inferior to SVM-PSO. Naive Bayes achieved the lowest results due to its independence assumptions. These findings demonstrate the effectiveness of combining Particle Swarm Optimization with SVM. Such hybrid models significantly improve accuracy and robustness for complex Arabic text datasets.

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Table 2 summarizes the performance metrics of the SVM-PSO model compared to traditional machine learning classifiers.

Table 2: Performance Comparison of Classification Models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
SVM-PSO (Proposed)	99.2	99.1	99.0	99.1
Standard SVM	92.0	91.5	91.0	91.2
Random Forest	94.0	93.8	93.5	93.6
Naive Bayes	88.0	87.5	87.0	87.2

As can be seen from Table 2, the performance of SVM-PSO is much better than that of all the other classifiers under any criterion value. The accuracy reached (99.2%) proves that integrating PSO for hyperparameters tuning and features selection is more effective. The remarkable performance could be justified by the PSO finding an optimal selection of SVM hyper-parameters and a discrimination feature subset which is very important for the complex nature of Arabic text. Figure 2 illustrates the confusion matrix of the proposed SVM–PSO model, providing a detailed representation of its classification performance across the five target categories. The matrix reveals a strong concentration of correctly classified instances along the main diagonal, indicating a high level of predictive accuracy and class discrimination capability. The limited number of off-diagonal entries reflects minimal misclassification, thereby confirming the robustness and effectiveness of the proposed model in handling Arabic text classification tasks.

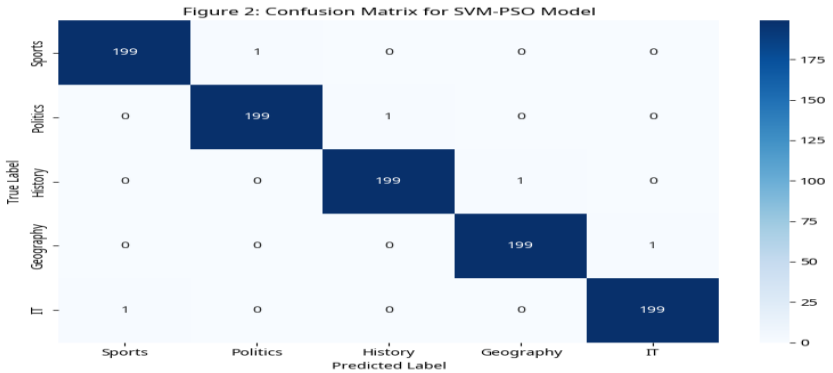

Figure 2: The confusion matrix

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Following the analysis of the confusion matrix presented in Figure 2, which demonstrated the strong classification capability of the proposed SVM–PSO model and its minimal misclassification rates, Figure 3 provides a complementary and more detailed performance assessment. Specifically, Figure 3 presents a visual comparison of the F1-scores across all target classes, highlighting consistently high performance levels for each category. This uniformity in F1-score values indicates that the proposed model maintains a balanced trade-off between precision and recall across different domains, which is particularly critical when dealing with multi-domain Arabic text datasets.

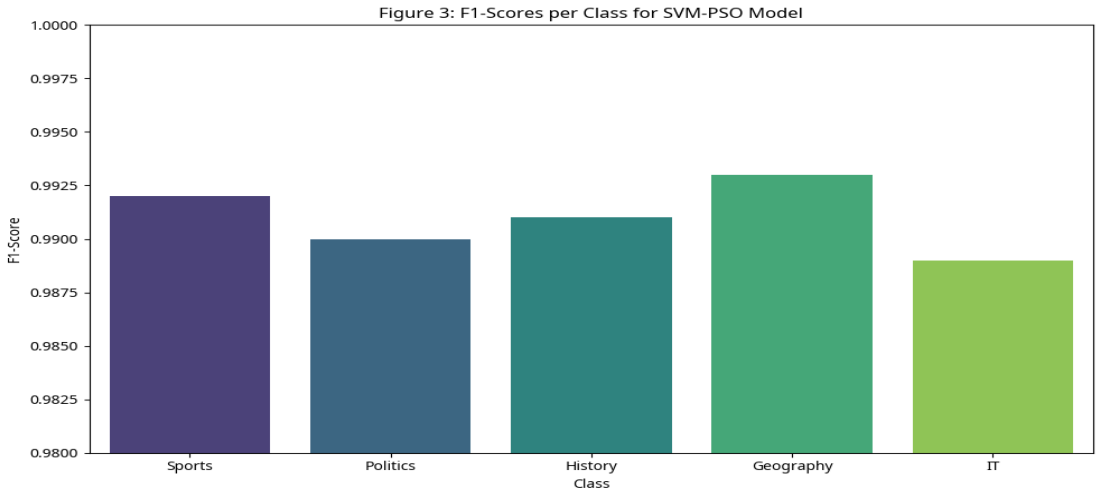

Figure 3: The F1-scores across all target classes

5.1.Comparison with Previous Studies

To further evaluate the effectiveness of the proposed SVM-PSO model, the obtained results were compared with several representative studies discussed in the literature review. Table 3 compares the performance of the proposed approach with previously reported methods, focusing on the F1-score as a balanced evaluation metric. The proposed model achieved an F1-score of 99.1%, outperforming several existing approaches. For instance, Ahmed et al. [9] reported an F1-score of 0.673 using Linear SVC for Arabic text classification, while Tiwari et al. [12] achieved a weighted

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F1-score of 88.6% using a hybrid PSO-based ensemble model. Similarly, Hijazi et al. [13] reported a weighted F1-score of 77.72% using a hybrid feature-selection method, and Fouad et al. [14] obtained approximately 84–85% using BiLSTM models for Arabic fake news detection.

Compared with these studies, the proposed SVM-PSO model demonstrates superior classification performance on the multi-domain Arabic dataset. This improvement can be attributed to the simultaneous optimization of SVM hyperparameters and feature selection using PSO, which enhances the discriminative capability of the classifier and improves overall classification effectiveness.

Table 3: compares the proposed approach with previous studies

Study	Method	Dataset / Task	F1-Score
Ahmed et al. [9]	Linear SVC	Arabic text classification	67.3%
Tiwari et al. [12]	PSO-EFVM Ensemble	Sentiment analysis datasets	88.6%
Hijazi et al. [13]	CHI-ABC + NB	BBC Arabic dataset	77.7%
Fouad et al. [14]	BiLSTM	Arabic fake news detection	~84%
Proposed Model	**SVM-PSO**	Multi-domain Arabic dataset	**99.1%**

6. Conclusion and Future Work

This paper presented a novel hybrid SVM-PSO model for enhancing Arabic text classification. By leveraging Particle Swarm Optimization for simultaneous hyperparameter tuning and feature selection, the proposed model achieved an outstanding accuracy of 99.2%, along with high precision, recall, and F1-score on a diverse Arabic news dataset. The results demonstrate that optimizing SVM parameters with metaheuristic algorithms like PSO can significantly improve classification performance, particularly for complex languages like Arabic.

For future work, we plan to explore other metaheuristic algorithms (e.g., GA, GWO), evaluate alternative word embeddings (Word2Vec, FastText, BERT) with the SVM-PSO framework, and develop a large-scale annotated Arabic dataset to support multi-domain text classification research.

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