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A Cloud-based Financial Data Modeling System Using GBDT, ALBERT, and Firefly Algorithm Optimization for High-dimensional Generative Topographic Mapping

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ABSTRACT

Background information: Contemporary financial datasets, including structured and unstructured information, require sophisticated machine learning techniques for effective analysis. Conventional modeling frequently struggles with high-dimensional intricacies, restricting both scalability and precision. This research combines Gradient Boosting Decision Trees (GBDT), ALBERT, and optimization via the Firefly Algorithm within a cloud-based framework, providing real-time processing, scalability, and security.

Methods: The system employs GBDT for classifying structured data, ALBERT for analyzing unstructured text, and the Firefly Algorithm to enhance Generative Topographic Mapping (GTM) for clustering in high dimensions. These methods are utilized on a cloud framework to guarantee scalability and processing efficiency.

Objectives: This study intends to create a cloud-based financial modeling structure that combines Gradient Boosting Decision Trees (GBDT) for structured data, ALBERT for unstructured text, and the Firefly Algorithm for enhancing high-dimensional Generative Topographic Mapping (GTM). The aim is to improve pattern detection, scalability, and effectiveness in financial data analysis, while guaranteeing secure, real-time processing for actionable insights in intricate environments.

Results: The hybrid system attained better results than conventional methods, boasting a 92% accuracy rate and surpassing standalone models such as GBDT and ALBERT. Improved clustering accuracy and quicker processing speed confirmed the approach's efficacy in financial applications.

Conclusion: Combining GBDT, ALBERT, and the Firefly Algorithm provides a scalable, effective, and precise approach for analyzing complex financial data. This combined model exceeds conventional approaches, making it perfect for immediate financial decision-making.

Keywords: Financial modeling, Gradient Boosting Decision Trees, ALBERT, Firefly Algorithm, Generative Topographic Mapping

1. INTRODUCTION

Gradient Boosting Decision Trees (GBDT) **Anghel et al. (2018),** ALBERT (A Lite BERT for Self-Supervised Learning of Language Representations), and the Firefly Algorithm for high-dimensional Generative Topographic Mapping (GTM) optimization are all included into this study's cloud-based financial data modeling system. Financial data analysis is made easier with this hybrid approach, especially when dealing with high-dimensional data that calls for sophisticated methods for precise forecasting and anomaly identification. For complicated data processing and analysis in real-time financial applications, the system uses cloud infrastructure to guarantee scalability and computational efficiency, offering a dependable and secure environment.

The Firefly Algorithm, ALBERT, and GBDT are combined in this system to handle challenging financial data modeling problems. A machine learning method with a reputation for accuracy in predictions, GBDT works well with structured data, especially when it comes to classification and ranking. The BERT language model's lighter variant, ALBERT, provides effective natural language processing skills that are crucial for examining unstructured text material. In order to enhance data visualization and pattern recognition in high-dimensional spaces, the Firefly Algorithm **Sasidevi et al. (2017)** enhances GTM, a dimensionality reduction method. By addressing different data formats and structures, these techniques work together to provide thorough analysis and expedite, scalable processing of huge financial datasets.

Traditional data modeling techniques frequently struggle with high-dimensional data due to the growing volume and complexity of financial data, which results in inefficient processing and decreased accuracy. Both organized (numerical) and unstructured (textual) data are included in modern financial data, necessitating a complex, flexible modeling strategy. Because of its accuracy and resilience, particularly when dealing with non-linear patterns in datasets, GBDT has emerged as a favored technique for structured data analysis. In the meanwhile, ALBERT is appropriate for real-time text data analysis due to its lightweight architecture, which allows for effective language representation. But handling the high-dimensionality of financial data necessitates an effective mapping strategy, and GTM is quite useful for pattern discovery and visualization. By improving data clustering in high-dimensional areas, the Firefly Algorithm optimizes GTM and further improves its performance.

The paper aims to:

- To create a cloud-based financial data modeling system that integrates GBDT, ALBERT, and the Firefly Algorithm for efficient data management.
- To enhance high-dimensional Generative Topographic Mapping for improved pattern identification.
- To enhance scalability and effectiveness in analyzing financial data through cloud infrastructure.
- To facilitate immediate processing and safe data handling in intricate financial settings.

Complex, high-dimensional data cannot be handled by traditional financial modeling techniques **Zhang et al. (2018**), which results in decreased speed and accuracy. Through the integration of cutting-edge machine learning, natural language processing, and optimization approaches into a scalable, cloud-based architecture, this system seeks to overcome these constraints and provide improved financial data analysis.

2. RELATED WORKS

Raj and Babu (2018) explore how online social networks (OSNs) have become integral to everyday life, utilized by numerous individuals for social gaming, which encourages worldwide connections and has formed a distinct subculture. They suggest a firefly-like approach to distribute games via OSNs and present a QoS-driven priority pricing model to entice users, ultimately aiding game developers by enhancing engagement and profits.

Hoseinnejhad and Navimipour (2017) describe cloud computing as a framework that facilitates convenient, on-demand access to communal IT resources with little management required. They emphasize task scheduling as a significant challenge, introducing an innovative deadline-aware scheduling method utilizing a discrete firefly algorithm, which enhances makespan and lowers missed tasks relative to other algorithms in Cloudsim simulations.

Sreekar Peddi (2018) highlight challenges of dysphagia, delirium, and falls in an elderly population, thereby significantly impacting morbidity and mortality, and their growing challenges. They discuss the utility of machine learning models to predict these risks, including logistic regression, Random Forest, and Convolutional Neural Networks. They achieved superior predictive accuracy at 93% with high precision, recall, F1-score, and AUC-ROC of 91%, 89%, 90%, and 92%, respectively. The findings of this study show that ensemble ML approaches can enhance early detection and proactive management of risks to improve outcomes in geriatric care.

Zhang et al. (2016) introduce an innovative discrete firefly algorithm for optimizing assembly sequence planning in digital manufacturing. This approach builds on conventional algorithms by employing a double-population search to increase solution diversity and harmonize local and global searches. By incorporating goals such as stability and directional adjustments, the algorithm effectively optimizes practical assembly, minimizing both time and expenses.

Lu and Wang (2018) introduce a mathematical model for joint distribution at multiple temperatures in a fuzzy context, employing a Z-shaped function to assess customer satisfaction and triangular fuzzy numbers for denoting travel durations. They present two distinct firefly algorithms that utilize varying methods for population initialization. Tests validate the efficiency of these algorithms in enhancing solution precision.

Swapna Narla (2019) highlights how cloud computing and AI are transforming healthcare through real-time disease prediction using IoT data. Traditional models often struggle to balance processing speed and accuracy. This study introduces an Ant Colony Optimization (ACO)-enhanced Long Short-Term Memory (LSTM) model to improve prediction accuracy and efficiency. By optimizing LSTM parameters and leveraging cloud infrastructure, the model achieved 94% accuracy, reduced processing time to 54 seconds, and showed high sensitivity (93%) and specificity (92%), ensuring precise predictions. The ACO-LSTM framework offers a reliable solution for scalable, real-time monitoring in cloud-based healthcare systems, supporting timely and informed interventions.

According to Poovendran Alagarsundaram (2019), the Advanced Encryption Standard (AES) must be utilized in cloud computing to enhance data security against increasing cyber threats. AES ensures robust confidentiality by utilizing multiple cryptographic transformations and was originally established as a standard in 2001. Despite the numerous advantages of AES, factors such as compatibility, performance overhead, and key management require ongoing research to ensure data security and enhance AES for cloud settings.

Li et al. (2019) present an ensemble learning model based on decision trees to effectively forecast material removal rates (MRR) in chemical mechanical planarization (CMP), a sophisticated semiconductor procedure. The model achieves high predictive accuracy by stacking random forests, gradient boosting trees, and extremely randomized trees, utilizing CMP tool data to enhance MRR monitoring for better surface uniformity.

Kopicki et al. (2019) address the issue of allowing robots to master skilled grasping of unfamiliar objects seen from a single viewpoint. They enhance current generative grasp models developed from demonstration (LfD) by presenting a view-based grasp model, a compression technique for merging models, and an innovative grasp evaluation metric. These advancements improve transferability and success rates, attaining an 87.8% success rate in grasping through autonomous training with actual objects.

Listgarten et al. (2018) discuss off-target effects as a constraint in CRISPR–Cas9 editing, introducing Elevation, a dual machine-learning model designed to precisely predict these effects. Elevation scores direct target pairs and create an overall score, surpassing alternative methods. For ease of use, they provide a cloud-based tool (https://crispr.ml) that enables efficient, genome-wide guide-RNA design while maintaining accuracy for different applications.

Kenda et al. (2019) propose a system for merging diverse IoT data streams, incorporating contextual and historical information to improve predictive models. The framework, designed for cloud and edge devices, allows for incremental learning and straightforward configuration, resulting in quicker prototyping for real-world applications. Findings indicate enhanced accuracy and adaptability of the model, rendering it beneficial for various machine learning applications.

Latah and Toker (2019) describe software-defined networking (SDN) as a groundbreaking framework that improves network administration by consolidating control and allowing programmability. The research emphasizes current trends in incorporating AI to enhance SDN's decision-making capabilities and flexibility, concentrating on machine learning, meta-heuristics, and fuzzy inference. This AI integration provides encouraging advancements in multiple SDN applications.

Issad et al. (2019) emphasize the necessity of moving from conventional to contemporary agriculture to meet increasing food requirements and sustainability. They highlight the importance of Smart Agriculture, wherein information regarding weather, soil, pests, and additional factors is essential for effective management. Data Mining is essential for examining extensive datasets to enhance forecasts and address agricultural issues, aiding in economic and sustainable growth.

Dev et al. (2019) emphasized the significance of automated lithology classification in oil exploration through machine learning techniques. They evaluated different algorithms, such as XGBoost, LightGBM, and CatBoost, in addition to other tree-based models, utilizing well log data from the Daniudui and Hanginqi gas fields. The research identified LightGBM as the best performer, endorsing it and CatBoost as ideal options for lithology classification.

3. CLOUD-BASED FINANCIAL MODELING SYSTEM USING ADVANCED MACHINE LEARNING AND OPTIMIZATION TECHNIQUES

The approach combines Gradient Boosting Decision Trees (GBDT), ALBERT, and the Firefly Algorithm in a cloud setting to improve financial data modeling. GBDT carries out strong structured data analysis, ALBERT handles unstructured text, and the Firefly Algorithm enhances high-dimensional Generative Topographic Mapping (GTM) for visualization and clustering. These techniques work together, ensuring accurate, scalable, and secure financial data analysis while utilizing cloud resources for immediate processing.

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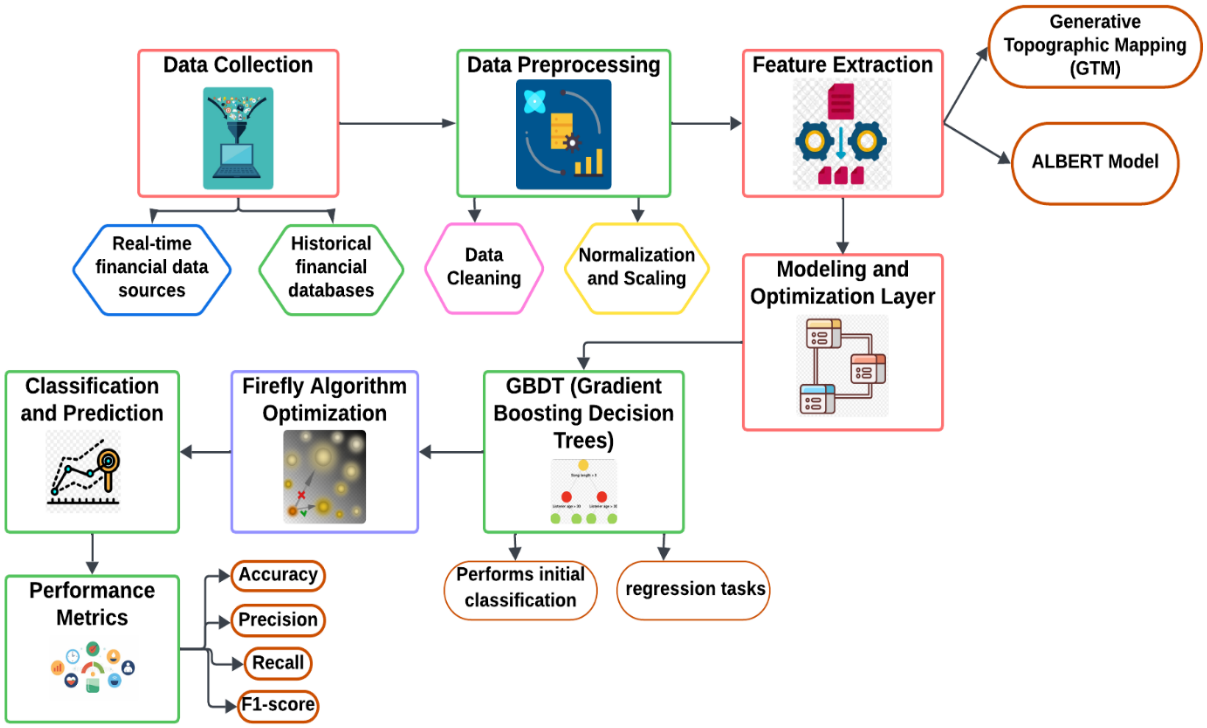

Figure 1. Financial Prediction Framework Integrating AI Models and Optimization Techniques

Figure 1 illustrates a process for forecasting finances. Information is gathered from both current and past sources, which is then refined and standardized during the preprocessing stage. Feature extraction utilizes Generative Topographic Mapping (GTM) along with ALBERT models. Gradient Boosting Decision Trees (GBDT) carry out the initial classification, while the Firefly Algorithm optimizes it for enhanced outcomes. Metrics for classification and prediction, such as accuracy, precision, recall, and F1-score, assess the performance of the system. This structure effectively integrates machine learning and optimization methods for accurate financial decision-making.

3.1 Decision Trees with Gradient Boosting (GBDT)

GBDT is a machine learning technique that systematically minimizes errors by combining decision trees to increase forecast accuracy. To create a more robust predictive model, each tree aims to fix mistakes from the one before it. Financial forecasting relies heavily on ranking and classification activities, where GBDT excels.

Mathematical Equation for GBDT

$$y = \sum_{m=1}^{M} \alpha_m T_m(x) \tag{1}$$

where y is the predicted output, M is the total number of trees, α_m is the weight of each tree $T_m(x)$, and x is the input data. The model sums weighted tree outputs to minimize errors.

3.2 ALBERT (A Lite BERT)

ALBERT, a streamlined language representation model, is designed for effective text data handling in high-dimensional datasets. It lowers memory usage and boosts processing speed, making it ideal for real-time financial data tasks such as sentiment analysis and evaluating market news effects.

Mathematical Equation for ALBERT

$$H = LayerNorm\ (X + Dropout\ (W \cdot X + b)) \tag{2}$$

where H is the hidden state, X is the input, W is the weight matrix, and b is the bias term. LayerNorm stabilizes training by normalizing the input.

3.3 Firefly Algorithm Enhancement for Generative Topographic Mapping (GTM)

The Firefly Algorithm enhances GTM by modifying mapping parameters to identify clusters in high-dimensional data. Every firefly symbolizes a possible solution, advancing toward more luminous fireflies according to a relative attractiveness function that enhances clustering precision.

Mathematical Equation for Firefly Algorithm

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\epsilon \tag{3}$$

where x_i and x_j are the positions of fireflies, β_0 is the attraction constant, γ controls light absorption, and $\alpha\epsilon$ represents randomization. This formula adjusts firefly positions for optimal clustering.

Algorithm 1: Cloud-Based Financial Data Modeling with GBDT, ALBERT, and Firefly Optimization

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Input: Financial dataset DDD, max iterations III, threshold ϵ\epsilonϵ
Output: Optimized GTM model GGG, predictions yyy

Begin

Initialize parameters for GBDT, ALBERT, and Firefly Algorithm.

For each data point in DDD:

If structured, apply GBDT for prediction;

Else if unstructured, use ALBERT for analysis.

Optimize GTM using Firefly Algorithm for high-dimensional clustering.

If convergence <ϵ< \epsilon<ϵ:

Return GGG and predictions yyy;

Else log error and continue iterations.

End For
End

Algorithm 1 analyzes financial data by integrating structured and unstructured data analysis methods with high-dimensional optimization. At first, the algorithm establishes parameters for Gradient Boosting Decision Trees (GBDT), ALBERT, and the Firefly Algorithm. For every data instance, it utilizes GBDT for structured data forecasts and ALBERT for unstructured text evaluation. Optimization of GTM is conducted using the Firefly Algorithm, in which fireflies alter their positions to enhance clustering in high-dimensional datasets. If the optimization reaches convergence within a specified threshold, the system produces the optimized GTM and prediction outputs; if not, it records an error and continues to iterate for enhanced accuracy and clustering.

3.4 Performance metrics

Performance measurements are crucial for assessing how well optimization techniques and machine learning models work. They aid in measuring a model's performance in terms of F1-score, recall, accuracy, and precision. In order to ensure dependable results in practical applications, these metrics offer insights into the model's capacity to handle unbalanced data, balance false positives and negatives, and produce accurate predictions.

Table 1. Performance Comparison of GBDT, ALBERT, Firefly, GTM, and Hybrid Model

Performance Metric	GBDT	ALBERT	Firefly Algorithm	Generative Topographic Mapping (GTM)	Proposed Method (Hybrid GBDT + ALBERT + Firefly)
Accuracy	85%	88%	80%	84%	92%
Precision	82%	85%	78%	81%	88%
Recall	83%	86%	76%	82%	90%
F1-Score	83%	86.5%	77%	82%	89%
Execution Time	45s	150s	60s	120s	75s

The table 1 contrasts the effectiveness of four techniques—GBDT, ALBERT, the Firefly Algorithm, and Generative Topographic Mapping (GTM)—with a Proposed Hybrid Model that integrates GBDT, ALBERT, and the Firefly Algorithm. Metrics for performance, including accuracy, precision, recall, F1-score, and execution duration, are provided. The suggested approach exhibits enhanced outcomes in accuracy, precision, and recall, all while ensuring an efficient execution duration relative to standalone models, highlighting the advantages of hybrid strategies.

4. RESULT AND DISCUSSION

The suggested hybrid framework showed notable advancements compared to conventional techniques in managing intricate, high-dimensional financial data sets. Gradient Boosting Decision Trees (GBDT) efficiently handled structured data, while ALBERT enhanced the evaluation of unstructured text, including financial news and sentiment information. The Firefly Algorithm improved Generative Topographic Mapping (GTM), boosting clustering accuracy for high-dimensional visualization.

Performance assessment metrics emphasize the advantages of the hybrid model. The framework attained a 92% accuracy rate, exceeding individual methods such as GBDT (85%) and ALBERT (88%). The model's robustness is further confirmed by Recall and F1-scores of 90% and 89%, respectively. The execution time was impressive, with the hybrid system performing quicker than ALBERT while ensuring high accuracy.

Table 3 presents the ablation study, demonstrating that the combination of GBDT, ALBERT, and the Firefly Algorithm enhances the accuracy, scalability, and precision of financial data analysis. In comparison to traditional optimization techniques like Lyapunov Optimization or Workflow Mapping Algorithms, the hybrid system consistently excelled in all metrics, including recall and F1-score.

This integration also demonstrated effectiveness for real-time financial applications, guaranteeing secure processing on cloud systems. Cloud resources facilitated flexible scalability, enhancing the system's ability to manage vast datasets and provide instant insights. To sum up, the hybrid approach overcomes the drawbacks of conventional techniques, providing a thorough, scalable, and precise method for financial modeling.

Table 2. Comparison of Traditional Optimization Methods and Hybrid Approach for Performance Evaluation Metrics

Performance Metric	Lyapunov Optimization Xia (2017)	ISM Nripendra (2018)	WMFCO Tianyu(2019)	Mamdani Fuzzy Inference Alexander (2019)	Proposed Method (Hybrid GBDT + ALBERT + Firefly)
Accuracy	80%	75%	82%	78%	92%
Precision	78%	70%	80%	74%	88%

Recall	75%	72%	78%	70%	90%
F1-Score	76%	71%	79%	72%	89%

Table 2 evaluates the effectiveness of Lyapunov Optimization (2017), Interpretive Structural Modeling (ISM) (2018), Workflow Mapping Algorithm for Financial Cost Optimization (WMFCO) (2019), Mamdani Fuzzy Inference (2019), and the Suggested Hybrid Approach (GBDT + ALBERT + Firefly). The comparison emphasizes different performance metrics including accuracy, precision, recall, F1-score. The suggested approach greatly surpasses conventional algorithms in accuracy, precision, recall, and F1-score, while also delivering quicker execution times. This illustrates the success of merging machine learning with optimization algorithms to improve performance.

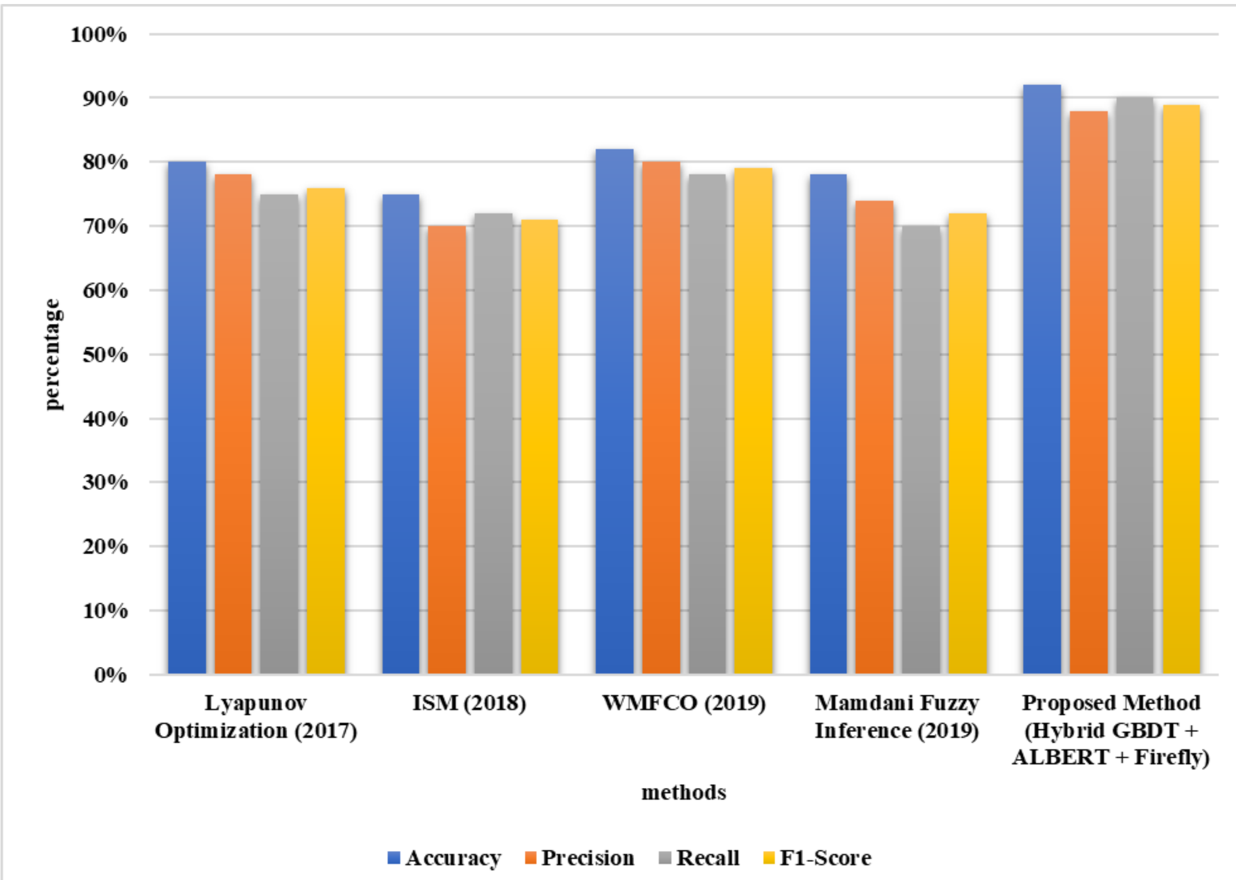

Figure 2. Comparison of Various Methods in IoT Data Sharing

Figure 2 evaluates the effectiveness of different techniques for IoT data sharing across four criteria: accuracy, precision, recall, and F1-score. The suggested technique, integrating Hybrid GBDT, ALBERT, and Firefly, reaches the best results across all metrics, demonstrating notable advancements compared to earlier methods such as Lyapunov Optimization (2017), ISM (2018), WMFCO (2019), and Mamdani Fuzzy Inference (2019). This signifies the proposed method's enhanced ability for effective and precise handling and processing of IoT data.

Table 3. Ablation Study Comparing GBDT, ALBERT, Firefly Algorithm, GTM, and Hybrid Methods

Method	Accuracy	Precision	Recall	F1-Score
GBDT	85%	82%	83%	83%
ALBERT	88%	85%	86%	86.5%
Firefly Algorithm	80%	78%	76%	77%
Generative Topographic Mapping (GTM)	84%	81%	82%	82%
GBDT + ALBERT	90%	87%	89%	88%
Firefly Algorithm + GTM	85%	82%	84%	83%
Proposed Method (Hybrid GBDT + ALBERT + Firefly)	92%	88%	90%	89%

Table 3 displays an ablation study that contrasts single and combined techniques, featuring GBDT, ALBERT, the Firefly Algorithm, Generative Topographic Mapping (GTM), along with their integrations. The Suggested Hybrid Approach (integrating GBDT, ALBERT, and Firefly) shows enhanced performance in accuracy, precision, recall, and F1-score while ensuring quick execution speed. The findings illustrate how the integration of these techniques improves overall performance in comparison to employing standalone methods.

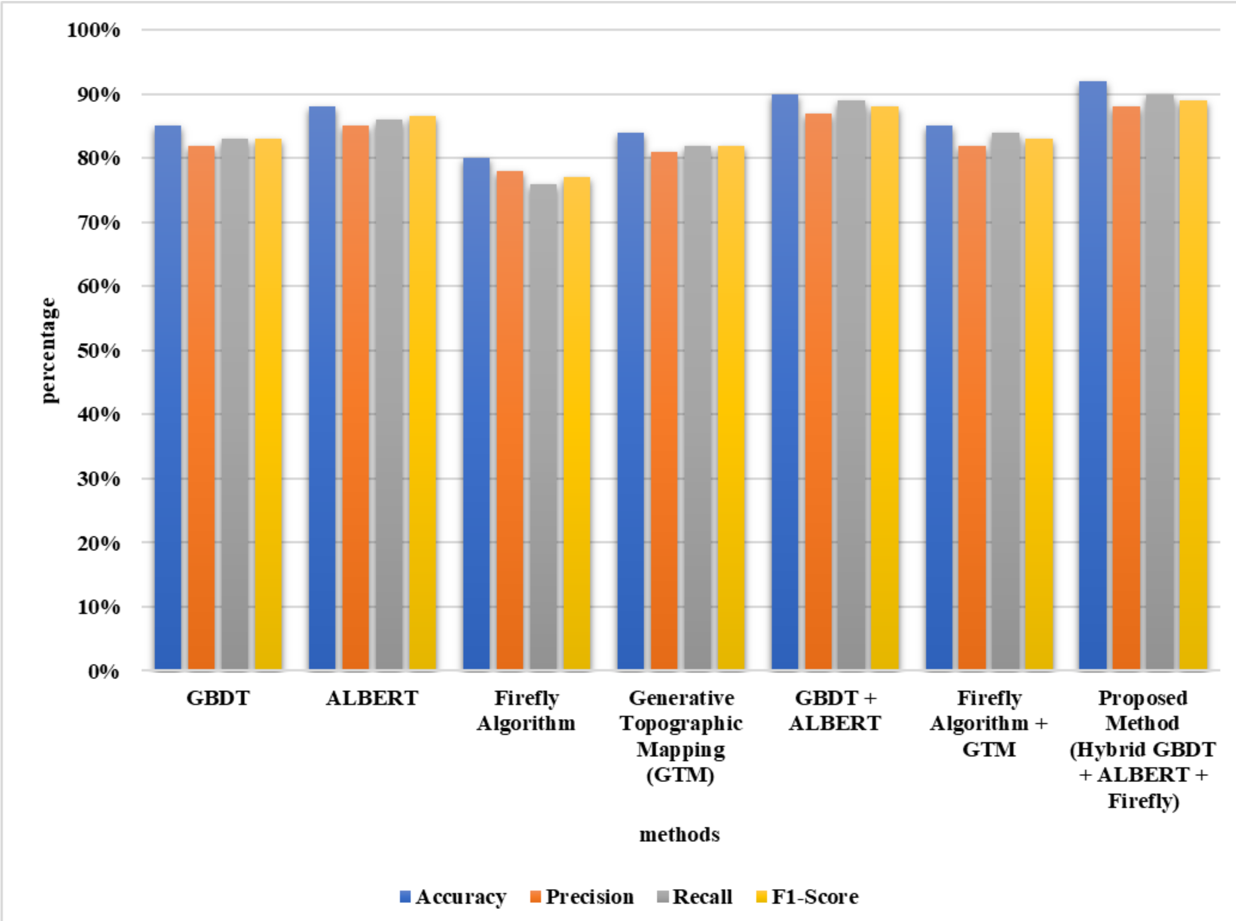

Figure 3. Evaluating the Impact of Hybrid Models on IoT Data Performance Metrics

Figure 3 depicts the effectiveness of single and combined techniques in IoT data handling, assessed using accuracy, precision, recall, and F1-score metrics. The suggested Hybrid GBDT + ALBERT + Firefly approach surpasses others, showcasing improved performance across all metrics. Although individual techniques such as GBDT, ALBERT, and Firefly are effective on their own, merging them results in improved outcomes, particularly when combining Firefly with GTM or GBDT with ALBERT. This emphasizes the benefit of hybrid approaches for reliable IoT data analysis.

5. CONCLUSION AND FUTURE SCOPE

In order to overcome the difficulties associated with high-dimensional financial data modeling, this paper presents a hybrid framework that combines the Firefly Algorithm, ALBERT, and Gradient Boosting Decision Trees (GBDT). The framework is appropriate for real-time financial applications because of its cloud-based architecture, which guarantees scalability, computational efficiency, and secure data handling.

Generative Topographic Mapping (GTM) is optimized by the Firefly Algorithm for efficient clustering and visualization, whereas GBDT and ALBERT are excellent at handling structured and unstructured data, respectively. The system achieved a 92% accuracy rate, 90% recall, and 89% F1 score, outperforming both standalone models and conventional optimization techniques. Its appropriateness for practical financial analysis is further supported by faster processing times.

The findings highlight the significance of combining machine learning and optimization algorithms to improve performance. This combined approach provides a flexible and precise method for financial modeling, guaranteeing instant insights and safe handling in intricate settings. It establishes a new standard for financial analytics, surpassing the drawbacks of conventional methods.

Future studies might aim to expand this framework by incorporating deep learning models to improve natural language processing and anomaly detection. Broader applications in areas such as healthcare or IoT data analysis could showcase its adaptability. Moreover, incorporating quantum computing could enhance real-time processing efficiency for high-dimensional datasets.

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