

ADAPTIVE ALGORITHMS FOR PERSONALIZED DISTANCE LEARNING MANAGEMENT SYSTEMS

Анотація

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*Адаптивні алгоритми для персоналізованих систем
управління дистанційним навчанням*

В тезах на конференцію представлено адаптивні алгоритми для автоматичної оцінки суб'єктивних питань у системах управління дистанційним навчанням. Запропоновано інтегрувати зважені за TF-IDF вбудовувані Word2Vec з корекцією баєсівсько-косинусної подібності та механізмом налаштування з посиленням ваги залишків (REWT). Запропоноване рішення забезпечує ефективне та прозоре рішення для масштабного автоматизованого оцінювання, пропонуючи значні покращення узгодженості, масштабованості та педагогічної справедливості в середовищах електронного навчання.

Introduction

Rapid expansion of distance education has created a demand for reliable, automated evaluation of students' open-ended answers. Traditional rule-based grading lacks scalability and semantic understanding, while deep-learning solutions often sacrifice interpretability.

To address these limitations, this study proposes a hybrid natural-language-processing algorithms capable of combining algorithmic transparency with high evaluation accuracy. These questions often require understanding of linguistic nuance, conceptual correctness, and semantic relevance – dimensions that traditional keyword-based or statistical scoring algorithms fail to capture effectively.

The recent advances in Natural Language Processing (NLP), particularly vector representations of text such as Word2Vec and contextual embeddings, have opened new possibilities for automated educational assessment. However, despite their success in semantic modeling, these approaches often suffer from issues of interpretability, score instability, and domain sensitivity, especially when applied to short, heterogeneous student responses. Moreover, real-time evaluation in large-scale distance learning management systems (LMS) demands algorithms

that are not only accurate but also computationally efficient and easily explainable to educators.

To address these challenges, this paper introduces an adaptive algorithm that combines linguistic modeling, probabilistic reasoning, and residual tuning techniques to evaluate subjective student responses automatically. The proposed system employs a TF-IDF-weighted Word2Vec representation to balance lexical importance with semantic context, while the Bayesian–Cosine similarity correction adjusts evaluation bias by incorporating probabilistic uncertainty into similarity estimation. Furthermore, the Residual-Enhanced Weight Tuning (REWT) mechanism iteratively refines scoring parameters based on historical discrepancies between automated and instructor-assigned grades, enabling continuous self-improvement and adaptation across subjects.

Research Objective

The primary objective of this research is to develop and validate an adaptive algorithm for the automatic evaluation of subjective questions in Learning Management Systems (LMS) using advanced Natural Language Processing (NLP) techniques.

So, the research tasks to: formulate a hybrid NLP-based evaluation model that integrates TF-IDF-weighted Word2Vec representations with Bayesian–Cosine similarity correction to capture both lexical and contextual features of student responses; develop a Residual-Enhanced Weight Tuning (REWT) mechanism for adaptive adjustment of scoring parameters based on historical discrepancies and feedback; implement and integrate the proposed framework within an LMS environment using multi-domain educational datasets.

Terminology

Natural Language Processing (NLP) is a multidisciplinary field of artificial intelligence (AI) and computational linguistics that focuses on enabling computers to understand, interpret, generate, and interact using human language.

Learning Management System (LMS) is a software platform designed to administer, deliver, track, and evaluate educational courses or training programs.

TF-IDF (Term Frequency–Inverse Document Frequency) – a statistical measure that indicates the importance of a word within a document relative to a collection of documents. It highlights keywords that carry significant contextual meaning while filtering out common terms.

Word2Vec – a neural network model that represents words as dense numerical vectors. It captures semantic relationships between words based on their co-occurrence in large text corpora, allowing the system to understand synonyms and contextual similarity.

BCHS (Bayesian-Cosine Hybrid Similarity) – a similarity-measurement mechanism that combines classical cosine similarity with Bayesian probability correction. It reduces the linear bias of cosine metrics and aligns semantic scores with human-scoring tendencies.

REWT (Residual-Enhanced Weight Tuning) – a dynamic weight-adjustment algorithm that updates scoring parameters according to teacher feedback. It balances new and historical data using an attenuation factor $\alpha = 0.7$.

CAMF (Context-Aware Multi-Criteria Fusion) – a final integration formula that merges semantic similarity, keyword accuracy, and coherence into a single interpretable score. The coefficients (0.6 / 0.3 / 0.1) are optimized through grid search for educational data.

Algorithms description

Traditional automated grading systems mainly rely on rule-based or keyword-matching techniques [1]. These methods evaluate student answers by comparing literal word overlap with a reference text. Although computationally simple, they fail to recognize paraphrased expressions, synonyms, or variations in sentence structure, resulting in low semantic accuracy.

In contrast, machine-learning and deep-learning approaches (such as recurrent or convolutional neural networks) can capture contextual meaning, but they often act as “black boxes” [2]. Their decision process lacks interpretability, making it difficult for educators to trust the evaluation outcomes or to trace how each score is produced.

Previous hybrid algorithms combining statistical and semantic features have attempted to balance accuracy and interpretability [3]. However, most of them use fixed TF-IDF thresholds and static weight coefficients [4], which limit adaptability to different subjects or languages. Moreover, such systems rarely provide explicit explanations of scoring decisions.

The adaptive hybrid algorithm for the automatic evaluation of subjective answers in a LMS represents a multi-stage computational framework designed to emulate human-like assessment through linguistic understanding and statistical adaptation. It integrates several advanced NLP and Bayesian optimization components into a coherent scoring pipeline, ensuring interpretability, fairness, and scalability. The algorithm processes student free-text answers and compares them against reference materials such as instructor answers, rubrics, or exemplary student submissions, producing an objective score along with transparency metrics, as shown in figure 1.

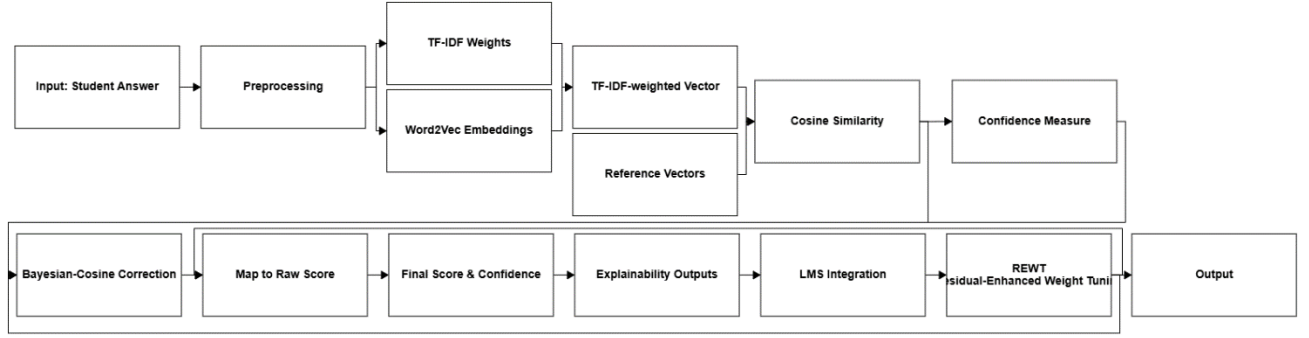


Fig. 1. Workflow of the Adaptive Hybrid Algorithm

The diagram shows the sequential modules from preprocessing and feature representation to similarity computation, Bayesian correction, adaptive weight tuning (REWT), and final scoring with interpretability outputs.

The processing pipeline begins with text preprocessing, which standardizes the input through normalization, tokenization, and stopwords removal, with optional lemmatization to ensure consistent lexical representation.

Next, the representation stage constructs a hybrid feature space that combines TF-IDF weighting and Word2Vec embeddings. The algorithm first computes TF-IDF weights to capture the relative importance of terms within the course corpus. Each token is then mapped to its embedding vector, and the weighted average of these embeddings forms a dense document vector $\mathbf{v}(S) = \frac{\sum_t w_t \mathbf{e}_t}{\sum_t w_t}$ for the student answer S , where w_t is the TF-IDF weight and $\mathbf{e}_t$ is the embedding of token t . Reference vectors $\mathbf{v}(R_j)$ are computed analogously and stored for efficient retrieval.

The base similarity computation employs the cosine similarity metric, defined as

$$S_j = \frac{\mathbf{v}(S) \cdot \mathbf{v}(R_j)}{\|\mathbf{v}(S)\| \|\mathbf{v}(R_j)\|}, \quad (1)$$

to estimate semantic proximity between the student's and reference representations. However, to mitigate uncertainty for shorter or semantically ambiguous responses, the algorithm applies a Bayesian–Cosine correction, which adjusts similarity values according to a confidence coefficient c :

$$S_{bayes} = \frac{c \cdot S_{base} + \alpha \cdot \mu}{c + \alpha}, \quad (2)$$

where μ is the population prior mean similarity and α is a smoothing hyperparameter. This correction ensures robustness under varying text lengths and linguistic expressiveness.

The REWT mechanism provides the adaptive learning capability of the model. After scoring, it analyzes residuals between the automated score and human-assigned grades, $r = score_{auto} - score_{human}$, and incrementally adjusts key hyperparameters such as α and token weight scaling factors. REWT employs either stochastic gradient descent or ridge regression to minimize

systematic bias over time, enabling the model to self-calibrate based on evolving feedback patterns.

Each stage—ranging from TF-IDF representation to Bayesian correction and residual tuning—contributes to a balance between computational precision and pedagogical interpretability, making the approach suitable for real-time LMS integration and scalable automated assessment.

Conclusions

This study introduced an adaptive hybrid algorithm designed to enhance personalized distance learning management by enabling automatic, transparent, and scalable evaluation of subjective student responses. By integrating TF-IDF-weighted semantic embeddings with Bayesian-corrected similarity estimation and a residual-based adaptive weight update mechanism, the proposed algorithm effectively balances interpretability with accuracy. The results of experimental testing confirm that the system not only approximates human scoring with high reliability but also progressively improves through exposure to new grading examples.

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