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COMPARISON OF MACHINE LEARNING AND REINFORCEMENT LEARNING FOR DEPRESSION RECOGNITION FROM SPEECH

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Abstract. Depression remains a critical global health issue, and early, accessible detection methods are essential for timely intervention. Human speech reflects not only verbal content but also subtle indicators of mental health, making it a valuable modality for non-invasive diagnostics. This study investigates the application of machine learning, particularly reinforcement learning (RL), for the automatic detection of depression from speech data. The research focuses on Mel-frequency cepstral coefficients (MFCCs) as primary acoustic features and evaluates the performance of several classification models, including logistic regression, support vector machines (SVM), LSTM networks, and Q-learning-based reinforcement learning. These models were tested under different data balancing scenarios: unbalanced, manually balanced, and SMOTE-enhanced datasets. The central hypothesis is that reinforcement learning, due to its ability to learn sequential decision-making strategies, can offer a robust approach for identifying depressive speech patterns. The results confirm that while traditional models perform well on balanced data, the reinforcement learning approach shows strong adaptability, achieving the highest F1 score of 0.658 and AUC-ROC of 0.628 in more challenging, imbalanced settings. These findings suggest the potential for RL-based systems

to support mental health assessment through passive speech monitoring. Future applications may include integration into mobile health platforms or telemedicine tools for early screening and continuous mental health tracking.

Key words: machine learning, reinforcement learning, natural language processing, depression detection, acoustic features.

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СӨЙЛЕУ АРҚЫЛЫ ДЕПРЕССИЯНЫ ТАНУ ҮШІН МАШИНАЛЫҚ ОҚЫТУ МЕН КҮШЕЙТУ АРҚЫЛЫ ОҚЫТУДЫ САЛЫСТЫРУ

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Аннотация. Депрессия – жаһандық денсаулық сақтау саласындағы өзекті мәселе болып табылады, ал оны ерте кезеңде анықтау – уақытылы көмек көрсету үшін өте маңызды. Адам дауысы тек айтылған сөздердің мазмұнын ғана емес, сонымен қатар адамның психикалық жағдайын сипаттайтын белгілерін де көрсете алады. Осы зерттеу жұмысы адамның дауыс деректерін пайдаланып, депрессияны автоматты түрде анықтау үшін машиналық оқытудың, соның ішінде күшейтілген оқытудың (reinforcement learning) мүмкіндігін зерттеу мақсат етеді. Талдау үшін негізгі акустикалық сипаттамалар ретінде мел-жиілік кепстральдық коэффициенттері (MFCC) пайдаланылды. Әртүрлі модельдердің нәтижелері – логистикалық регрессия, тірек векторлық тәсілі (SVM), LSTM және Q-оқытуға негізделген күшейтілген оқыту – теңгерілмеген, қолмен теңгерілген және SMOTE әдісімен теңгерілген деректер жиынтығында салыстырылды. Сонымен қатар, бұл әдістерді қолдануда деректер теңгерімсіздігінің әсері мен деректерді алдын ала өңдеу тәсілдерінің маңыздылығы ескерілді. Басты гипотеза – күшейтілген

оқыту әдістері, шешім қабылдаудың ретті стратегияларын үйрену қабілеті арқылы, депрессия белгілерін сөйлеу арқылы тиімді анықтай алады. Нәтижелер көрсеткендей, дәстүрлі әдістер теңгерілген деректермен жақсы жұмыс істегенімен, күшейтілген оқыту моделі теңгерілмеген деректерде ең жоғары F1 көрсеткішіне (0.658) және AUC-ROC мәніне (0.628) қол жеткізді. Зерттеу нәтижелері адамның психикалық жағдайын дауыс арқылы анықтауға арналған шешім қабылдау жүйелерін әзірлеуде күшейтілген оқыту модельдерін қолдану әлеуетінің жоғары деңгейде екенін көрсетеді. Бұл тәсілдерді қолдану болашақта мобильді денсаулық сақтау платформаларына немесе телемедицина жүйелеріне біріктіріліп, ерте скрининг пен психикалық денсаулықты үздіксіз бақылауға мүмкіндік беруі мүмкін.

Түйін сөздер: машиналық оқыту, күшейту арқылы оқыту, табиғи тілді өндіру, депрессияны анықтау, акустикалық белгілер.

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СРАВНЕНИЕ МАШИННОГО ОБУЧЕНИЯ И ОБУЧЕНИЯ С ПОДКРЕПЛЕНИЕМ ДЛЯ РАСПОЗНАВАНИЯ ДЕПРЕССИИ ПО РЕЧИ

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Аннотация. Депрессия остается серьезной глобальной проблемой здравоохранения, и для своевременного вмешательства необходимы доступные методы раннего выявления. Речь человека отражает не только смысл сказанного, но и содержит тонкие признаки психоэмоционального состояния, что делает ее ценным источником для неинвазивной диагностики. В данном исследовании рассматривается применение методов машинного обучения, в частности обучения с подкреплением, для автоматического выявления депрессии по аудиоданным речи. Основу анализа составляют мел--частотные кепстральные коэффициенты (MFCC), по которым оценивалась эффективность различных моделей классификации, включая логистическую регрессию, метод опорных векторов (SVM), LSTM-сети и обучение с подкреплением на базе Q-обучения. Эти модели были протестированы на

несбалансированных, вручную сбалансированных и сбалансированных с помощью SMOTE наборах данных. В исследовании также учитывались аспекты предварительной обработки аудиосигналов и балансировки классов, что оказывает значительное влияние на конечные результаты. Основная гипотеза заключается в том, что обучение с подкреплением, благодаря своей способности обучаться последовательным стратегиям принятия решений, может быть эффективно применено для выявления признаков депрессии в речи. Результаты показали, что несмотря на высокую эффективность традиционных моделей на сбалансированных данных, подход на основе обучения с подкреплением достиг наилучших значений F1-метрики (0.658) и AUC-ROC (0.628) при работе с несбалансированными данными. Полученные выводы указывают на высокий потенциал использования RL-моделей для оценки психоэмоционального состояния по речи. Возможными приложениями являются интеграция в мобильные платформы здравоохранения и системы телемедицины для раннего скрининга и непрерывного мониторинга психического здоровья.

Ключевые слова: машинное обучение, обучение с подкреплением, обработка естественного языка, выявление депрессии, акустические признаки.

Introduction. Depression, recognized globally as a major mental health concern, affects approximately 280 million people of all ages, severely impacting daily functioning and contributing significantly to the global burden of disease. Early detection and intervention are crucial in managing depression, yet traditional diagnostic methods are often resource-intensive and reliant on self-reported data, which can be subjective and vary in accuracy. (Ribeiro, et al., 2019; Lin, et al., 2020; García, et al., 2021; Hill, et al., 2017; Jankowsky, et al., 2023; Rejaibi, et al., 2022)

Table 1. Depression prevalence across different groups

Demographic Group	Prevalence of Depression	Additional Information
General Population	3.8%	280 million people globally
Adults	5%	4% among men, 6% among women
Adults Older Than 60 Years	5.7%	
Women Compared to Men	50% more common	
Pregnant Women & New Mothers	>10%	Worldwide among pregnant women and women who have just given birth

Speech analysis using machine learning offers a promising avenue for such technological advancements. Human speech carries rich information not only about the content of communication but also about the speaker's psychological state, making it a valuable medium for potential early diagnosis of mental health

issues. Recent studies suggest that various speech features, such as tone, pitch, and rhythm, may change significantly due to psychological distress, potentially serving as indicators of depression. (Rejaibi, et al., 2022; Shin, et al., 2021; Tasnim, et al., 2022; Low, et al., 2020)

This paper focuses on the automated detection of depression from speech using machine learning techniques. By utilizing the DAIC-WOZ dataset (Gratch, et al., 2014), which includes audio recordings from clinical interviews, the study aims to develop models that can accurately identify depressive speech patterns. The primary objective is to create a system that can be applied in real-world scenarios, such as call centers, telehealth services, or mobile health applications, where the availability of only audio data makes traditional diagnostic methods impractical.

Materials and methods.

Background

Traditional methods for diagnosing depression typically involve clinical evaluations and self-reported questionnaires. While these approaches are valuable, they often depend on the patient's willingness and ability to accurately report their symptoms, which may not always be consistent or reliable due to the stigma associated with mental health disorders or the subjective nature of self-assessment. (Ribeiro, et al., 2019; Lin, et al., 2020; García, et al., 2021; Hill, et al., 2017; Jankowsky, et al., 2023; Rejaibi, et al., 2022)

Recent advances in natural language processing (NLP) have attempted to address some of these limitations by analyzing spoken or written language content to detect signs of depression. However, these approaches are often constrained by language-specific factors, such as vocabulary and grammar, making them less effective in multilingual or non-native English-speaking populations. Moreover, NLP techniques primarily focus on the semantic content of speech, potentially missing non-verbal cues that can be equally, if not more, indicative of a person's mental state. (Sakib, et al., 2021; Fodeh, et al., 2019; Liu, et al., 2022; de Oliveira, et al., 2022)

In contrast, speech analysis focuses on the acoustic and prosodic features of speech, which are less dependent on language and can provide a universal set of biomarkers for detecting depression. Speech characteristics such as tone, pitch, rhythm, and energy levels can reflect underlying emotional states and cognitive processes. For instance, research has shown that depressed individuals often exhibit slower speech rates, lower pitch variability, and reduced energy in their voice, all of which can be quantitatively measured and analyzed. (Rejaibi, et al., 2022; Shin, et al., 2021; Tasmin, et al., 2022; Low, et al., 2020)

This research aims to build on these foundations by employing the DAIC-WOZ dataset, which offers a rich source of audio recordings from clinical interviews specifically designed to assess psychological distress. (Gratch, et al., 2014

Mel-Frequency Cepstral Coefficients (MFCC) have been chosen as the primary feature for this study due to their proven efficacy in capturing the essential

characteristics of human speech. Studies have demonstrated that MFCC features effectively capture changes in voice quality, pitch, and energy, which are critical markers of depression. Moreover, MFCCs have been widely used in emotion recognition and mental health diagnostics, showing robust performance across various tasks, making them a suitable choice for detecting depressive tendencies in speech. (Rejaibi, et al., 2022)

In this comparative study, a reinforcement learning approach was introduced and evaluated alongside other machine learning methods. The RL model demonstrates particular utility in scenarios requiring periodic decision-making, where its ability to learn from sequential data offers significant advantages. This approach opens new avenues for research in the mental health domain, particularly for applications where adaptive and continuous learning can enhance diagnostic accuracy.

Dataset Collection

The DAIC-WOZ (Distress Analysis Interview Corpus - Wizard of Oz) dataset (Gratch, et al., 2014) comprises high-quality audio recordings, visual recording (facial expression and body language), transcriptions and PHQ-9 questionnaires from 193 participants.

For this research, the focus was solely on the speech data, as the primary aim was to analyze vocal patterns and features relevant to detecting depression. By concentrating on speech analysis, the study aimed to develop models that could potentially be used in real-world applications, such as call centers or mobile health apps, where only audio data might be available.

Preprocessing and Feature Extraction

Noise reduction was performed using the librosa and noisereduce libraries to enhance the signal-to-noise ratio, ensuring cleaner speech signals for more accurate feature extraction.

The audio recordings were segmented based on the duration of participants' responses after the questions were asked. The segmentation process involved:

- **Identifying Speech Segments:** Detecting the start and end points of each participant's response within the audio recordings.
- **Filtering Short Segments:** Ignoring segments shorter than 160 samples to maintain data quality. Short segments often contain insufficient information for meaningful analysis.
- **Ensuring Minimum Segment Length:** Setting the minimum segment length to 1120 samples to ensure sufficient data for analysis. This threshold was chosen based on empirical observations and the need for adequate feature extraction.

Normalization was performed using StandardScaler and that ensured all features contributed equally to model training by standardizing their scales.

Mel-Frequency Cepstral Coefficients (MFCCs) were extracted from each segment. The extraction process included windowing with a size of 1120 samples,

applying FFT, using a mel filter bank, followed by logarithm and DCT to obtain MFCCs.

The parameters for this extraction included a window size (n_fft) of 1120 samples and a hop length (hop_length) of 560 samples (half of n_fft). The mean MFCC for each segment was calculated to represent the vocal features of each participant.

Balancing the Dataset

Handling Imbalanced Dataset

The initial dataset exhibited class imbalance, with approximately 70% negative (non-depressive) and 30% positive (depressive) segments. Class imbalance is a common issue in medical datasets, where the prevalence of certain conditions (e.g., depression) is naturally lower than others. An imbalanced dataset can lead to biased models that favor the majority class, reducing the model's ability to detect the minority class (depressive segments).

To address this imbalance, the number of segments for each class was adjusted to create a balanced dataset in the following two different ways:

- **Undersampling the Majority Class:** Reducing the number of negative segments to match the number of positive segments.
- **Oversampling the Minority Class:** Increasing the number of positive segments through data augmentation techniques.

By balancing the classes, the model was trained on an equal number of positive and negative segments, reducing bias and improving its ability to detect depressive speech patterns.

Undersampling the Majority Class

Some of the samples from the majority class were removed to reduce the oversampled class and balance the dataset. This operation removed the samples of the majority class randomly.

Oversampling the Minority Class

The Synthetic Minority Over-Sampling Technique (SMOTE) creates new, synthetic observations from present samples of the minority class. Python SMOTE library was used to oversample the minority class.

Models Used

To do this comparative analysis based on speech, various machine learning and reinforcement learning approaches were employed. The models used in this study include Logistic Regression, Support Vector Machine (SVM), Long Short-Term Memory (LSTM) networks with different preprocessing techniques, and a Q-learning reinforcement learning algorithm using leaky ReLu activation function. Both imbalanced and balanced datasets were utilized to evaluate the performance of each model.

Table 2. Long Short-Term Memory (LSTM) Model

Layer	Params
Hidden Layer: 64	Regularization: L1 = 0.01, L2 = 0.01, Return_Sequence = True
Output Layer: 2	SoftMax

Table 3. Reinforcement Learning (Q-learning with Leaky ReLu Activation Function)

Layer	Params
Hidden Layer: 128	Batch Normalization, Leaky ReLu = 0.01
Hidden Layer: 64	Batch Normalization, Leaky ReLu = 0.01
Output Layer: 2	Linear

Reinforcement Learning Environment & Reward Function

In the RL model, the observation space is represented by the MFCC feature array derived from the audio data. This array's shape corresponds to the dimensions of the extracted MFCC features for each audio segment. The action space is discrete, containing two possible actions: 0, indicating no suicidal tendency, and 1, indicating the presence of suicidal tendencies.

The reward function is designed to provide feedback based on the accuracy of the model's predictions. If the model's action (predicted label) matches the correct label (ground truth), a positive reward of +1 is given, reinforcing the correct prediction. Conversely, if the predicted action does not match the correct label, a negative reward of -1 is applied, penalizing incorrect predictions. This encourages the model to improve its decision-making by aligning its actions with the correct labels over time.

Results

In this study, the performance of various machine learning models was evaluated, including Logistic Regression, Support Vector Machine (SVM), Long Short-Term Memory (LSTM) networks with Batch Normalization and StandardScaler, and a Q-learning-based Reinforcement Learning model, across different dataset balancing strategies: imbalanced, manually balanced, and balanced using the SMOTE technique. The metrics used to assess performance were accuracy, F1 score, precision, recall, specificit , and AUC-ROC. In the context of mental health diagnostics, particular emphasis is often placed on metrics like AUC-ROC, precision, and recall, as they better reflect the models' ability to identify and prioritize at-risk individuals correctly. (Ribeiro, et al., 2019; Lin, et al., 2020; García, et al., 2021; Shin, et al., 2021; Sakib, et al., 2021)

The goal was to assess the effectiveness of these models in detecting depressive speech patterns based on simple input data such as Mel-Frequency Cepstral Coefficients (MFCCs), without applying any additional feature engineering. The results are summarized and compared below.

Performance on Imbalanced Dataset

For the imbalanced dataset, both Logistic Regression and SVM demonstrated relatively low performance in terms of F1 score and recall, with F1 scores of 0.036 and 0.0, respectively. While these models maintained decent accuracy

(0.692 and 0.697, respectively), their inability to effectively identify the minority class (depressive segments) was evident, as shown by their near-zero recall rates. The AUC-ROC scores for these models were also low, with Logistic Regression achieving 0.514 and SVM 0.478, indicating poor overall discrimination between classes.

The LSTM models, while slightly better than Logistic Regression and SVM in terms of F1 score and recall, still struggled with the imbalanced dataset. The LSTM with Batch Normalization achieved an F1 score of 0.272 and a recall of 0.244, while the LSTM with StandardScaler had an F1 score of 0.202 and recall of 0.149. Despite slightly better performance, the AUC-ROC values for these models were still below optimal, reflecting the challenges posed by the imbalanced dataset.

Reinforcement Learning using the Q-learning algorithm was applied to the imbalanced dataset, yielding noteworthy results. The Q-learning RL model achieved an F1 score of 0.3759 and a remarkably high recall of 0.8227, significantly outperforming the other models in identifying the minority class. However, the precision was relatively low at 0.2436, indicating a higher rate of false positives. The AUC-ROC for the Q-learning model was 0.4552, which is lower than that of Logistic Regression and SVM, suggesting that while the model is effective at detecting the minority class, its overall ability to discriminate between classes is limited using the imbalance dataset.

Table 4. The metrics comparison on the imbalanced dataset

Model	F1 Score	Precision	Recall	AUC-ROC
Logistic Regression	0.0362	0.3592	0.0191	0.5145
SVM	0	0	0	0.4779
LSTM (Batch Normalization)	0.2724	0.3080	0.2442	0.5057
LSTM (StandardScaler)	0.2016	0.3124	0.1488	0.4891
Q-learning RL	0.3759	0.2436	0.8227	0.4552

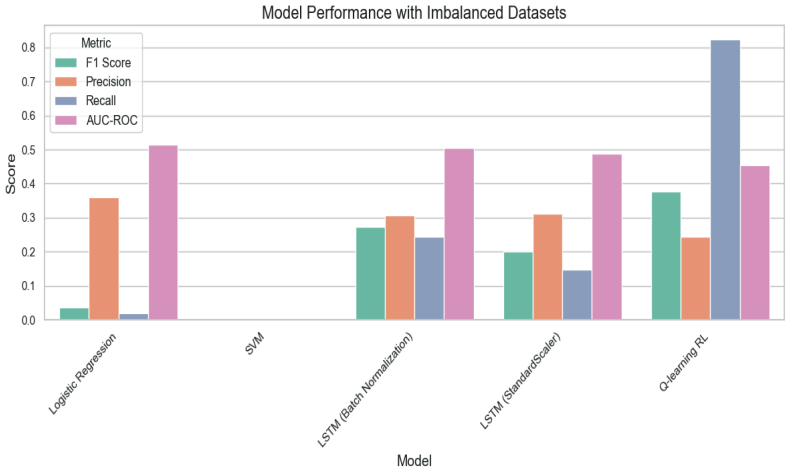

Figure 1. Model performance with imbalanced datasets.

Performance on balanced Dataset (using SMOTE)

On the SMOTE-balanced dataset, both traditional machine learning models and LSTM variants showed a decline in performance compared to manually balanced data. Logistic Regression achieved an accuracy of 0.477, an F1 score of 0.390, and an AUC-ROC of 0.639, indicating moderate improvements in recall (0.551) but lower precision (0.302). Similarly, SVM had an accuracy of 0.452, an F1 score of 0.394, and an AUC-ROC of 0.638, showing a similar trade-off with improved recall (0.588) but reduced precision (0.297). The LSTM models struggled more, with the Batch Normalization variant reaching an accuracy of 0.465, an F1 score of 0.382, and an AUC-ROC of 0.481, while the StandardScaler version achieved an F1 score of 0.385 and an AUC-ROC of 0.475, indicating that SMOTE balancing led to instability in the LSTM performance.

Reinforcement Learning using the Q-learning algorithm was applied to the SMOTE-balanced dataset, yielding notable results. The Q-learning RL model achieved an F1 score of 0.5185, a precision of 0.4661, a recall of 0.5842, and an AUC-ROC of 0.4445. Compared to the other models, the Q-learning model demonstrated a higher F1 score and precision, indicating better overall performance in predicting depressive segments. However, the AUC-ROC value was lower than those of the traditional models, suggesting that while the Q-learning model was effective in identifying the minority class, its overall ability to discriminate between classes was limited. This highlights that SMOTE may not be the ideal balancing technique for speech data in this context, where temporal dependencies and nuances are critical.

Table 5. The metrics comparison on the dataset balanced by SMOTE

Model	F1 Score	Precision	Recall	AUC-ROC
Logistic Regression	0.3901	0.3019	0.5512	0.6390
SVM	0.3944	0.2966	0.5883	0.6376
LSTM (Batch Normalization)	0.3817	0.2938	0.5445	0.4813
LSTM (StandardScaler)	0.3849	0.2878	0.5812	0.4750
Q-learning RL	0.5185	0.4661	0.5842	0.4445

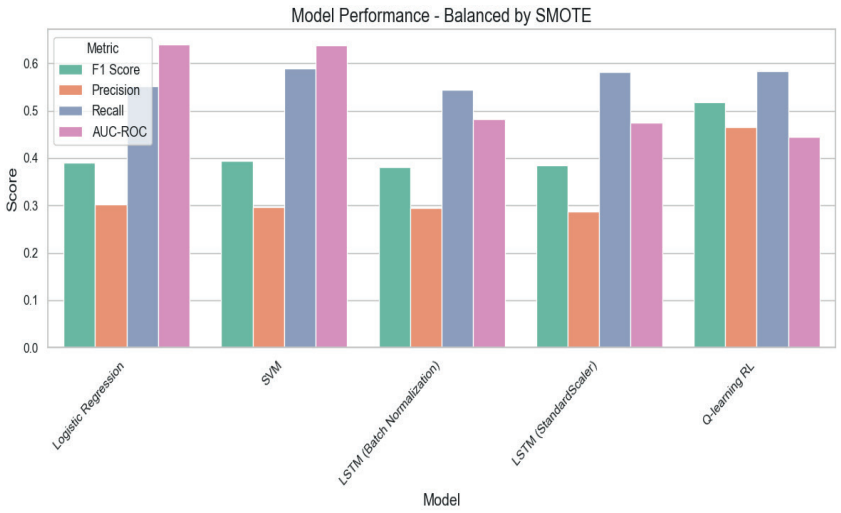

Figure 2. Model performance with dataset balanced by SMOTE.

Performance on balanced Dataset (by reducing oversampled class)

On the manually balanced dataset, achieved by reducing the oversampled class, all models demonstrated improved performance compared to the imbalanced dataset. Logistic Regression reached an accuracy of 0.571 and an F1 score of 0.606, showing significant gains in recall (0.659) but with a moderate drop in specificity (0.483). SVM exhibited similar improvements, with an F1 score of 0.605 and an AUC-ROC of 0.639, indicating a better balance between recall (0.674) and precision (0.549). The LSTM models, while more effective, were still unstable. The LSTM with Batch Normalization achieved an F1 score of 0.412 and an AUC-ROC of 0.505, but its accuracy (0.506) and recall (0.346) lagged behind. The LSTM with StandardScaler performed better, with an F1 score of 0.526, accuracy of 0.495, and an AUC-ROC of 0.514, showing more balanced results between precision and recall. Notably, the Q-learning RL model outperformed the traditional models, achieving an F1 score of 0.658 and a recall of 0.951, although its low specificity (0.062) highlighted its tendency to over-predict depressive cases. These results suggest that reducing the oversampled class helps models balance precision and recall, particularly benefiting RL in sequential decision-making tasks.

Table 6. The metrics comparison on the dataset balanced by reducing oversampled class

Model	F1 Score	Precision	Recall	AUC-ROC
Logistic Regression	0.6061	0.5607	0.6594	0.6402
SVM	0.6049	0.5487	0.6739	0.6390
LSTM (Batch Normalization)	0.4120	0.5094	0.3459	0.5055
LSTM (StandardScaler)	0.5258	0.4957	0.5598	0.5136
Q-learning RL	0.6583	0.5034	0.9509	0.6285

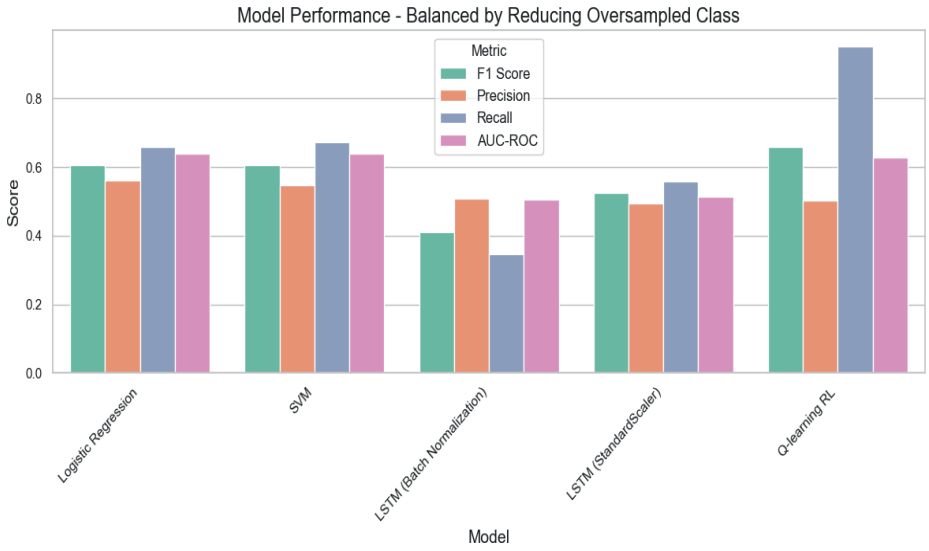

Figure 3. Model performance with dataset balanced by reducing oversampled class.

Discussion

The results of this study highlight several areas for improvement and future research directions. First, while the Q-learning reinforcement learning (RL) model showed promise, particularly on the manually balanced dataset, it exhibited poor specificity and instability on other datasets. This suggests that more advanced RL models should be explored. Future work could include more complex RL architectures, such as Deep Reinforcement Learning (Deep RL) or hybrid models that combine RL with other machine learning techniques like LSTM or CNN, to better capture the temporal and sequential aspects of speech data.

Additionally, the current approach used simple Mel-Frequency Cepstral Coefficients (MFCCs) as the sole input features. To improve model performance, more sophisticated vocal features should be engineered and incorporated. These could include prosodic features (pitch, intonation, rhythm), voice quality measures, or even features derived from deep learning-based speech embeddings. Combining these advanced features with a more complex RL model could lead to more accurate and robust depression detection.

In summary, future research should focus on incorporating highly engineered vocal features and exploring more sophisticated RL models, potentially in combination with other machine learning methods, to enhance both precision and recall in depression detection from speech.

Conclusion

This study explored the feasibility of detecting depression from speech using machine learning and reinforcement learning methods, focusing on MFCCs as primary input features. By systematically comparing traditional classifiers with a

Q-learning-based reinforcement model across various data balancing strategies, the research highlights both the challenges and potential of voice-based mental health diagnostics. While traditional models demonstrated competitive results on manually balanced data, reinforcement learning showed strong performance in identifying depressive segments, particularly under imbalanced conditions. These findings underscore the promise of reinforcement learning in sequential, adaptive tasks such as mental state assessment. Future work may benefit from integrating multimodal inputs or refining reward strategies to enhance diagnostic accuracy in real-world applications.

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