Assist Dyslexic Children in Improving Readability Using Advanced Machine Learning Techniques

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Abstract:- Lorem Dyslexia is a learning disorder common in children, characterized by difficulties with reading and language processing skills. Children with Dyslexia often need more time to process these skills than their peers. Early intervention can help mitigate these challenges. Dyslexia, often identified in children at an early age, poses challenges in decoding letters, recognizing sounds, understanding alphabets, and related skills. This study concentrates on enhancing the reading proficiency of dyslexic children, specifically in the Punjabi language. The research targets children above six years old who encounter difficulties in reading and exploring various hardware and software techniques to address these issues. The study entails recording 13,000 audio samples containing both accurate and inaccurate pronunciations of two and three-letter Punjabi words. These audio samples serve as the primary input for the system. To achieve this goal, a dataset comprising Punjabi words pronounced by children of diverse age groups through visits to different schools and then system trained using this dataset. Children will be presented with a set of words to read. If they pronounce a word incorrectly, the system will provide the correct speech, aiding in the training of the children. In essence, this paper presents a prototype model to support dyslexic children in enhancing their reading skills, with a specific focus on the Punjabi language.

Keywords: Recurrent Neural Network, Convolutional Neural Network, Dyslexia, Speech Recognition, Machine Learning, MFCC, LSTM, Dyslexia.

1. Introduction

The term "dyslexia" describes a learning difficulty commonly found in children, affecting their reading, alphabet recognition, speech, writing, and related skills. Dyslexia isn't an illness but rather a congenital condition, often having a hereditary link. Its main challenge lies in recognizing phonemes, making it tough for these children to blend sounds into words and recognize common words.

Children with Dyslexia face multiple challenges. For instance, Attention Deficit Hyperactivity Disorder (ADHD) impacts their reading and other activities. Executive functioning issues affect organizational skills, thinking abilities, and memory. Slow processing speed hinders reading, especially basic skills and comprehension. Auditory Processing Disorder (APD) affects their ability to discern letter sounds, while visual processing issues result in blurry vision, letter reversals, and writing difficulties. Dysgraphia affects spelling and number formation, and Dyscalculia leads to math difficulties. Executive functioning issues broadly impact various learning aspects, including organizational skills and memory. Slow processing speed significantly affects reading, creating challenges in basic skills and comprehension.

The paper concentrates on reading disorders observed in dyslexic children, particularly their struggle with word decoding. They are reading hinges on connecting sounds with letters, which is crucial for accurate and fluent reading. This paper specifically targets dyslexic children aged above six years, aiming to comprehend and address their challenges in reading development.

2. Research Approaches to Dyslexia

This review paper critically examines the various research avenues related to Dyslexia, as well as the challenges and issues that arise. The authors discuss different prediction methods proposed by researchers, which are machine learning techniques, game-based strategies and assistive tools. Numerous methods have been specifically crafted to support children with Dyslexia, including software-based solutions and hardware interventions. The following section will delve into a comprehensive discussion of these approaches:

The study involved 35 participants aged 10-12. It used a five-minute reading test and content analysis for assessment. Additional evaluations included various tests such as sentence chains, non-word assessments, word reading, and picture identification. Apps like Prizmo, TTS, Easy Writer, and Voice Reader were utilized. Two games were also developed: a word puzzle and a word-guessing game based on provided letters. However, extensive use of multiple apps might have affected the training structure. Traditional reading test tools and the questionnaires used might need to align fully with the study's focus and aims [1]. Class Dojo is a tool teachers use to monitor and evaluate student behavior, having two primary components. The first part awards badges—positive or negative—based on factors like concentration, coping skills, handwriting, reading ability, independent work, and self-confidence. The second aspect is a reporting system that logs these badges. Its advantages lie in offering interactive experiences through gamification and promoting exploratory learning approaches.

Nevertheless, a drawback of Class Dojo is its reliance on a traditional, time-consuming method to assign badges [2]—an adaptive clustering algorithm to improve phone recognition by reducing complexity and enhancing accuracy. Phonemes are grouped into clusters, and recognition involves identifying clusters using hidden Markov models (HMMs). Training patterns are used for feature extraction, and K-means clustering categorizes phonemes for HMM-based recognition. Teachers record native speakers' pronunciation, and students compare their pronunciation against set parameters. This assesses pronunciation quality based on sound, tempo, volume, and pronunciation. It aids in improving phonetic skills and allows error correction. In the future, this approach could be useful for independent pronunciation practice in asynchronous learning environments [3]. Assist students struggling with recognizing specific Malay letters ('p', 'q', 'b', 'd', 'm', and 'w'). Using balloons to captivate attention and clapping as a reward for success, it operates on mobile devices, employing a multisensory approach to focus on alphabet identification and memorization. However, a limitation is that it provides feedback from experts rather than being specifically designed for dyslexic students [4]. To boost English language skills, including phonological awareness, reading, and writing. It incorporates three methods: alphabet letter reading, letter copying, and reading paragraphs aloud, practised for a two-week duration.

Utilizing Hidden Markov Model (HMM) techniques and game middleware, it visualizes the alphabet. An advantage lies in its demonstrated improvement rate exceeding 60%. However, a downside is its potentially time-consuming aspect during learning. Implementing complex HMM techniques might also require added effort and expertise [5]. This approach is designed to automatically detect off-task behaviours, such as engaging in irrelevant activities or talking during learning sessions. It uses the Least Square (LS) machine learning algorithm to predict 34 identified off-task behaviours. The method incorporates tutoring software with animations and audio. However, one limitation is the observed relatively low rate of improvement in children using this approach, suggesting the need for further enhancements to increase its effectiveness [6]. Targets cognitive and behavioural challenges, specifically enhancing reading and writing skills by employing a gaming approach with captivating characters to augment learning. Through game-based activities like word segmentation and sentence completion, knowledge visualization is promoted, contributing to improved performance. A lesson planner, utilizing machine learning and crowd-sourcing, tailors activities based on the child's existing knowledge. However, a drawback is the need for more evaluation regarding its effectiveness and underlying model, necessitating further research and assessment to determine its efficacy. Future evaluation of learning speed and facilitated rate could provide valuable insights into its overall effectiveness and efficiency [7].

Three implementation stages: in Phase 1, features are classified using a decision tree algorithm to identify predictors. Phase 2 introduces Lexa, an application built using the Bootstrap framework, HTML, CSS, and JavaScript. Notably, Lexa doesn't replace current dyslexia tests but serves as a parental tool. It includes two tests: the Rise test, where children select animals producing varying tones, and the Oddity test, requiring the selection of non-rhyming words from buttons. A challenge in prototype development was sound creation, addressed by hosting Lexa on the cloud for sound assessment and playback via mobile devices [8]. Recognize spoken words using lip pattern analysis via a USB camera, considering factors like frame rate, distance, lighting, and frames per word. It employs a haar cascade for sample classification and intensity equalization based on pixel values and lip boundaries. Key point extraction identifies specific lip points, and edge tracking matches lip movements with a database for word identification using neural network algorithms. It offers automatic key point recognition crucial for practical lip reading, aided by neural networks managing large datasets and reducing errors. However, challenges may arise in intensity equalization due to uneven lighting and non-uniform intensity distribution. A solution could involve using LVQ (Learning Vector Quantization) neural networks to enhance accuracy by mitigating quantization errors [9]. Native Greek children and 32 dyslexic children diagnosed by government agencies are all facing learning and reading challenges. Various statistical features were considered, and classification methods like Native Bayes, Support Vector Machines (SVM), and K-means were applied. Performance assessment involved mean and median saccade length, movements, and fixations on the screen. Two reading tasks were provided, measuring fixations and their distances (900 pixels indicating fewer deficiencies, 100 pixels indicating more). SVM exhibited a 97% performance rate. An advantage was exploring word properties beyond direct eye-tracking parameters.

Yet, the DyslexML approach, using a smaller feature set, may limit the analysis scope. The study sets the groundwork for a screening tool applicable to a larger population, comparing different techniques' strengths and weaknesses in a table [10]. Jollymate, a specialized notepad, aids dyslexic students in self-learning by accurately recognizing handwritten characters, acting as a digital tool to bolster letter-writing skills. Using Lipi IDE as a character recognition system, the notepad processes input written by the child and sends it to the Lipi toolkit for comparison with training samples via a neighbour classifier. Correct matches prompt audio feedback and convert the letter into a star symbol, while mismatches provide audio feedback and display an interactive touch screen for letter practice. This innovative device is primarily geared towards enhancing letter-writing skills and overall learning abilities [11]. Correctly written letters earn stars, while incorrect ones trigger extra exercises on the app's touch screen.

Handwritten recognition algorithms, such as KNN (K-Nearest Neighbors) and NN (Neural Networks), are utilized to distinguish between accurate and incorrect letter recognition. However, this tool is specifically designed for children with writing difficulties, limiting its applicability to a specific group. Looking forward, there is potential to expand this tool to aid children with reading difficulties. It could recognize letters based on the child's reading and classify them using algorithms like KNN or NN [12].

Aerobic language learning employs Hidden Markov Models (HMMs) in automatic speech recognition. Aimed at children aged 5 to 10, it introduces letters with proper writing styles. Children can use the microphone icon to record their speech, receiving feedback indicating correct pronunciation or asking for repetition. However, a limitation is the need for more discussion on potential application challenges in this paper. In the future, assessing the learning success rate could offer valuable insights into the effectiveness of this technique [13].

They are improving Hindi word readability for dyslexic children aged five to seven using software and hardware techniques. It trains 600 Hindi word sounds with the Dynamic Time Warping (DTW) algorithm. Various machine learning algorithms like K-Means, K-Nearest Neighbor, Adaptive Clustering, LS Algorithm, Support Vector Machine, and Hidden Markov Model are examined to enhance speech features and reading accuracy. The system, trained on two and three-letter Hindi words, allows dyslexic children multiple attempts at word reading and achieves 90%-100% accuracy with familiar users and 30% with new users, indicating potential for personalized learning but challenges in broader application [14].

Table 1:-Comparative Analysis

Sr. No.	Paper Title	Technique	Advantage	Drawback
1.	Assistive technology as a reading intervention for children with reading impairments with a one-year follow-up	TTS, reading tests, word puzzles, Easy writing, Voice reader	Assistive technology for independent learning using a smartphone	Traditional techniques with less training are structured and sequential
2.	Using gamification to motivate students with Dyslexia.	Special Educational Needs, Class dojo as exploratory approach, awarding badges,	opportunities using gamification to motivate students with Dyslexia	traditional and time-consuming method
3.	A Multimedia English Learning System Using HMMs to Improve Phonemic Awareness for English Learning	adaptive clustering, HMM in specifies clusters, K-means, Error correction	Multimedia English learning promotes phonetic ability.	Only for English learning
4.	'Dyslexia Baca' Mobile App-The Learning Ecosystem for Dyslexic Children	"Dyslexia baca" mobile app, ADDIE model ,	multisensory Malay language approach, human-computer interaction	Only for Malay language, feedback from experts not to dyslexic students
5.	Integrative assistive system for dyslexic learners using hidden Markov models.	HMM techniques combined with game middleware, Assistive intelligent model	Integrated Assistive System for improvement in dyslexic children.	It is time-consuming, and it is only for the English language.
6.	Automatic detection of off-task behaviours in intelligent tutoring systems with machine learning techniques	Least Square and RIDGE REGRESSION technique, intelligent tutoring systems, detect students' off-task behaviours.	Machine learning model Animation and audio used to identify students' off-task behaviours	Less improving rate, complex, not better identify the behaviour of students
7.	The learners game: support for students with Dyslexia in class and at home	Game software system, model using machine learning,	visualize knowledge personalized teaching programme improves performance in reading and writing	No evaluation model plays the game outside school.
8.	Mobile application to support Dyslexia diagnostic and reading practice	Dragon Mobile SDK prototyping-based methodology,	Diagnosis of dyslexic people speaking in brazil language	Only for brazil language
9	A novel approach for lip reading based on neural network	Learning vector Quantization neural network	Lip reading provides an additional advantage of achieving high accuracy, minimizes quantization errors	Non-uniform intensity, only for ten Hindi words

10	DysLexML: Screening Tool for Dyslexia Using Machine Learning	Screening tool, linear SVM model, Native Baye's and K means	DysLexML screening tool is high performance in the presence of noise for Greece dyslexic peoples	Smaller feature set, only for Greece language
11	Jollymate: Assistive technology for young children with Dyslexia	Lipi toolkit IDE, Multisensory learning using machine learning (k-NN &NN)	Specialized notepad is applied to teach children with Dyslexia about letter sounds and formation.	It is only helpful for writing letters
12	YUSR: Speech Recognition Software for Dyslexics	Analyzing phonetics based on the Hidden Markov Model toolkit and Mel-Frequency Cepstral Coefficients	YUSR is used for the recognition of 28 Arabic letters to improve the reading skills of dyslexic children	application only for Arabic letters
13.	A Computer-Based Method to Improve the Spelling of Children with Dyslexia	DysEggxia, a word-puzzle game for iPad basics on TALE scores	To support and improve writing skills in Spanish	only focus on writing in Spanish
14.	Advanced Machine Learning Techniques To Assist Dyslexic Children For Easy Readability	MFCC, Dynamic Time Warping	Support dyslexic children in Hindi, higher accuracy for a known user	only for 30 Hindi words, low accuracy for new user

3. Speech Recognition

Recognizing speech involves the conversion of spoken language into text or actionable commands, and the process unfolds through several key steps:

a) Audio Capture: Employ a microphone or similar audio input device to record spoken phrases or words.

b) Preprocessing: Elevate audio quality by executing tasks such as noise reduction, filtering, and normalization of the captured audio.

c) Feature Extraction: Derive pertinent features from the preprocessed audio, such as Mel Frequency Cepstral Coefficients (MFCCs), spectrograms, or other time-frequency representations capturing the nuances of speech signals.

d) Acoustic Modeling: Train or deploy a pre-trained acoustic model to understand the relationship between the extracted audio features and speech sounds. Models like Hidden Markov Models (HMMs), Deep Neural Networks (DNNs), Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), LSTM, or Transformer-based models are commonly utilized.

e) Language Modeling: Implement a language model to grasp the context and enhance accuracy by predicting word sequences based on the detected speech. This involves statistical methods, n-grams, or advanced approaches like recurrent neural networks or transformers.

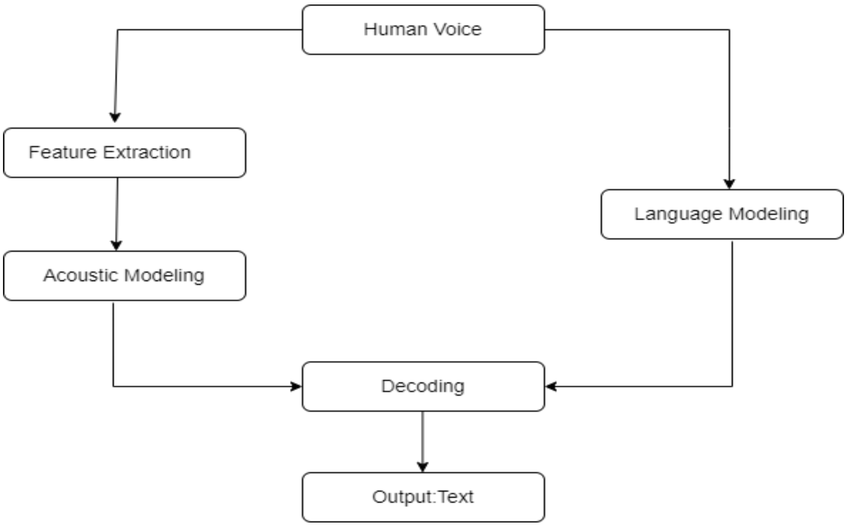
f) Decoding: Combine acoustic and language models in a decoding process, utilizing algorithms like Viterbi or beam search to generate the most probable word sequence corresponding to the input speech.

g) Post-processing: Apply techniques to refine the recognized text, correct errors, and overall improve accuracy

h) Output Generation: Produce the recognized text or commands as output, which can be displayed as text, used as input for further application processing, or employed to trigger specific actions based on the identified speech.

The comprehensive speech recognition process integrates signal processing techniques, machine learning, and natural language processing methods to precisely transcribe spoken words or commands into text or actionable data. The specific details and intricacies may vary based on the nature of the speech recognition system or application.

Figure1: Speech Recognition system steps: Speech to Text



4. Machine Learning Techniques for Speech Recognition

4.1 Convolutional Neural Networks

CNN is utilized in speech recognition tasks by processing audio spectrograms as two-dimensional representations. They capture patterns in these spectrogram images, aiding in tasks like phoneme recognition, speech transcription, and keyword spotting. While CNNs play a role in analyzing audio data, other models like RNNs or hybrid architectures such as CRNNs are also popular for capturing temporal dependencies in speech recognition

4.2 Mel-GAN

Mel-GAN is a specialized Generative Adversarial Network (GAN) primarily used to generate high-quality audio signals, particularly in the speech and music domains. It focuses on creating audio waveforms based on Mel Spectrograms, representations of the audio frequency spectrum over time. By employing adversarial training, Mel-GAN aims to produce realistic audio samples by generating Mel Spectrograms and converting them back into audio waveforms. This model has been influential in tasks like speech synthesis, music generation, and audio enhancement.

4.3 Recurrent Neural Networks

RNNs are specialized neural networks designed for handling sequential data, such as time series or language. They maintain hidden states to retain past inputs, which is beneficial for tasks where context is crucial. Challenges arise due to issues like vanishing or exploding gradients, limiting their understanding of long-term dependencies. Despite this, RNNs have extensive applications in language tasks, time series prediction, and speech recognition. The development of newer architectures like LSTMs and GRUs aimed to address gradient problems and enhance RNNs' ability to learn from longer sequences.

4.3.1. Long Short-Term Memory

LSTMs excel in speech recognition by processing audio features sequentially, capturing long-term dependencies. These networks utilize stacked layers to learn patterns, followed by dense layers mapping to desired outputs, like phonemes or words. Supervised learning trains them to minimize differences between predictions and actual targets. During inference, the model predicts speech units or transcriptions for new inputs. LSTMs specialize in handling sequential data and learning intricate patterns, while newer models like Transformers also offer competitive capabilities in this domain.

4.3.2. Gated Recurrent Unit

GRU is a specialized form of recurrent neural networks (RNNs) for sequential data processing. Similar to LSTMs but with a simpler architecture, GRUs efficiently capture long-range dependencies in sequences. They are well-suited for tasks like natural language processing, speech recognition, and time series prediction. These units include gated components that regulate information flow, aiding in better memory retention and more efficient handling of sequential data compared to standard RNNs.

4.4. Connectionist Temporal Classification

In speech recognition, CTC is an algorithm in machine learning for sequence-to-sequence tasks like speech and handwriting recognition. CTC is useful when the alignment between input and output sequences isn't known in advance. For example, in speech recognition, the length of audio input may not match the transcription length. CTC addresses this by introducing a "blank" label, allowing flexible alignment learning during training. This algorithm helps train neural networks to map input sequences (e.g., audio spectrograms) to output sequences (e.g., transcriptions) without requiring precise alignment during training. It's widely used in automatic speech recognition (ASR) systems to convert spoken language into written text.

4.5 Transformer

The Transformer architecture, initially crafted for natural language processing, has been repurposed for speech recognition in models like the Transformer Transducer. It retains the encoder-decoder structure with self-attention, featuring causal masking in the decoder for autoregressive generation. The model commonly integrates CTC for flexible alignment during training and undergoes joint training on CTC and sequence-to-sequence objectives. Positional encoding is used to signify input sequence positions. This adaptation effectively captures long-range dependencies in speech, highlighting the versatility of the Transformer architecture across tasks.

4.6. Hidden Markov Models

HMMs are vital for speech recognition, as they model the temporal dynamics and acoustic probabilities of phonemes. Phonemes are represented through states and transition probabilities within HMMs, which also integrate language models to enhance accuracy. Trained using labelled speech data and algorithms such as EM, and HMMs decode speech using the Viterbi algorithm. Adaptation techniques further refine HMM parameters for specific users or environments, underscoring their significance in converting speech to text.

Table 2. Existing Assistive tools for dyslexic children

Software	Function	Tech.
Jollymate	Multisensory learning using machine learning (k-NN &NN)	Digital notepad
Kurzweil 3000	Scan reading material and read out to them	TTS
MyBaca	Sentence reading	courseware
Dyslexia Baca	Confusion of letters by using Multisensory and Memorizing methods	Mobile app
YUSR	Speech recognition, alphabet, and phonemes based	software

	on the HMM model of machine learning	
WordQ	Writing tool, suggest words, speech feedback	TTS
Helpread	Read-along software while users are reading	TTS
Read, please	Read aloud text from web pages/emails	TTS
Dragon naturally speaking	Dictation software	ASR
Via voice	Dictation software	ASR
Mylexic	Dual coding theory, scaffolding teaching strategy, provide alphabet, syllables, word learning module	CD courseware
IASD	Phonological awareness, HMM model used	Standalone soft.
iLearnRW	Student model by using machine learning	Game software system
Clicker 4	Word processing support	TTS
TextHelp	Suggestion of spelling when typing, read aloud writing for checking	TTS
E-Talk	Phoneme tone awareness	device
Go phonics	Software to teach reading to dyslexic children based on the Orton-Gillingham method provides tests and assessments.	CD-ROM
Language tune-up kit	Software to teach reading to dyslexic children based on the Orton-Gillingham method teaches grammar, punctuation, and the rules.	CD-ROM

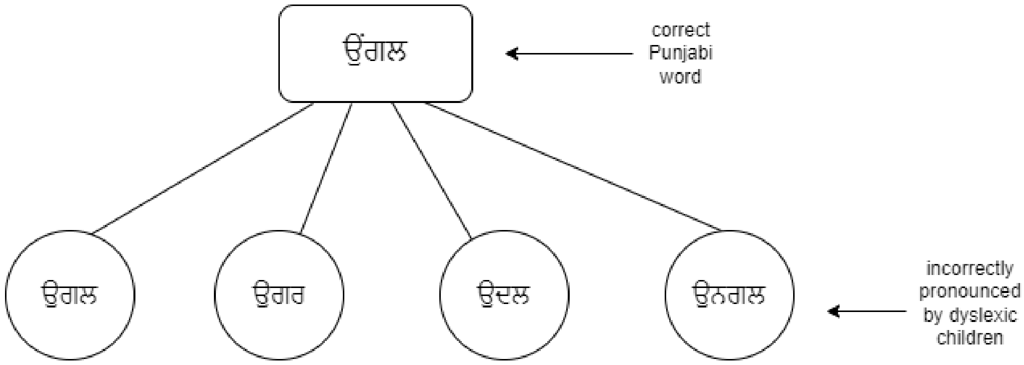
5. Dataset

This study focuses on Dyslexic Punjabi children who have difficulties in reading and struggle with word recognition. The dataset comprises recordings of approximately 13000 Punjabi words pronounced both correctly and incorrectly by children in primary up to middle school between the ages of 7 and 18. Therefore, the participation of 24 children

Figure 3: Image during data collection in school

encompasses 14 boys and ten girls, with each child contributing the same Punjabi word seven times. The dataset consists of speech data collected from children attending different schools in the state of Punjab in districts Sangrur and Mansa. Begin by acknowledging that dyslexic children can pronounce a single word in four or five incorrect ways. The study revolves around facilitating the learning process for dyslexic children in Punjabi, specifically in word recognition.

Figure 2: Punjabi word differently pronounced by dyslexic children



6. Use libraries/ Packages in Speech Recognition :

6.1. MFCC

MFCCs, crucial for tasks such as speech recognition and speaker identification in audio processing, are derived through pre-emphasis, frame segmentation, windowing, FFT for magnitude spectrum, and Mel filterbank for energy across frequency bands. Logarithmic transformation aligns the results with human ear sensitivity. Decorrelation is achieved via DCT, resulting in MFCCs. The preservation of initial coefficients highlights essential spectral features. These coefficients prove versatile in diverse audio analyses, offering effectiveness in customized applications like speech recognition and speaker identification with tailored parameters.

6.2 Librosa

Librosa, a Python package initially designed for music and audio analysis, finds utility in specific aspects of speech recognition tasks. Although not explicitly tailored for automatic speech recognition (ASR), librosa serves as a versatile tool for audio preprocessing and feature extraction. It facilitates the loading and preprocessing of audio files, converting them into numerical representations and extracting various audio features, including Mel-Frequency Cepstral Coefficients (MFCCs) commonly employed in speech recognition. Librosa also supports the creation and visualization of spectrograms, providing insights into the frequency content of speech signals. While librosa is valuable for certain preprocessing steps, it's essential to recognize that comprehensive ASR systems typically leverage dedicated libraries and frameworks like Kaldi or DeepSpeech for more extensive functionality in constructing end-to-end ASR solutions.

6.3 Kaiser-Fast

Kaiser-Fast, a specialized window function for audio resampling in speech recognition, precisely balances frequency resolution and sidelobe suppression, refining the traditional Kaiser window. It plays a crucial role in adjusting audio recordings to specific sample rates, contributing significantly to the resampling process. Renowned for minimizing abrupt changes and reducing spectral leakage, the Kaiser window enhances accuracy in speech recognition. As a swift and computation-focused variant, Kaiser-Fast efficiently approximates the Kaiser window, excelling in both accuracy and efficiency. Its key strengths include maintaining frequency resolution, suppressing sidelobes, and minimizing computational demands, making it a valuable tool for accurate and efficient speech recognition systems.

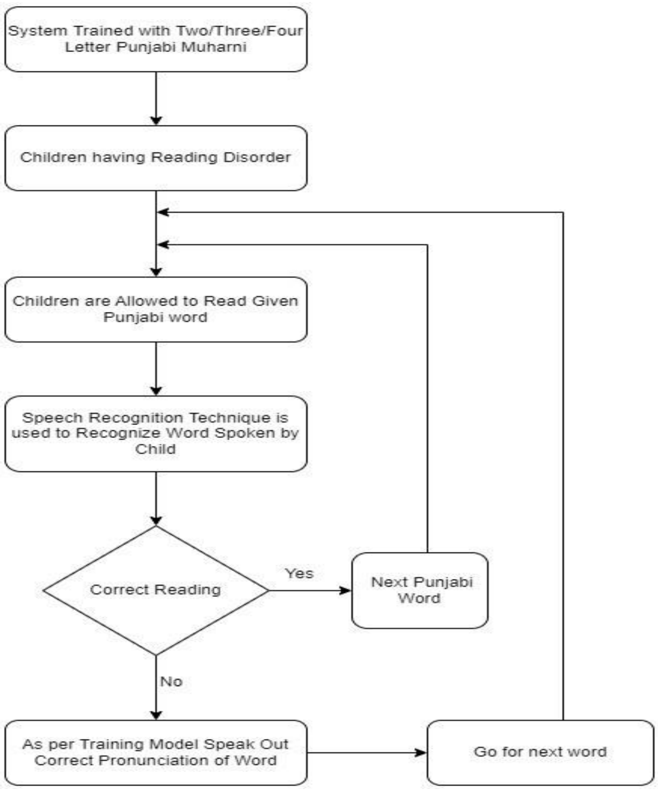
6.4. Softmax

Softmax is essential in speech recognition neural networks, transforming raw scores into probabilities that add up to 1. After processing audio features, it is utilized to generate probabilities for different classes, such as phonemes or words. Frameworks like TensorFlow smoothly incorporate this function into model design. The predicted class is based on the highest probability. Customize the architecture and parameters to fit the requirements of your speech recognition task.

7. Discussion and Conclusions:

The paper assesses tools for dyslexic children, emphasizing algorithms like K-Means, K Nearest Neighbor, Adaptive Clustering, LS Algorithm, Support Vector Machine, Hidden Markov Model, Convolutional Neural Networks, RNN, LSTM, Gated Recurrent Unit, Connectionist Temporal Classification and Transformer and use libraries Packages in Prototype Model. These algorithms enhance speech recognition accuracy for children over six years old with Dyslexia by extracting and refining speech features. The research aims to support dyslexic children by applying machine learning algorithms to create a tailored technique. The system trains with two and three-letter Punjabi words and interacts with the child. If the child mispronounces a word, the system audibly articulates the correct pronunciation, aiding word recognition. Considering the existing assistive techniques, the focus is on creating a support system for Punjabi dyslexic children to enhance their learning experience. Following the model's development, we will assess its accuracy and effectiveness. We anticipate that our proposed system will exhibit a significantly improved accuracy rate, establishing it as a valuable tool for dyslexic children learning Punjabi.

Figure 4: A prototype model for assisting Dyslexic Children



References:

[1] Lindeblad, E., Nilsson, S., Gustafson, S., & Svensson, I. (2017). Assistive technology as reading interventions for children with reading impairments with a one-year follow-up. *Disability and rehabilitation: assistive technology*, *12*(7), 713-724.

[2] Gooch, D., Vasalou, A., Benton, L., & Khaled, R. (2016, May). Using gamification to motivate students with dyslexia. In *Proceedings of the 2016 CHI Conference on human factors in computing systems* (pp. 969-980).

[3] Lai, Y. S., Tsai, H. H., Yu, P. T., & Hsu, J. M. (2007, April). A multimedia learning system using hmms to

improve phonemic awareness for english pronunciation. In *2007 International Conference on Multimedia and Ubiquitous Engineering (MUE'07)* (pp. 1064-1069). IEEE.

[4] Daud, S. M., & Abas, H. (2013, December). 'Dyslexia Baca'Mobile App--The Learning Ecosystem for Dyslexic Children. In *2013 international conference on advanced computer science applications and technologies* (pp. 412-416). IEEE.

[5] Ndombo, M. D. (2013). Integrative assistive system for dyslexic learners using hidden Markov models.

[6] Cetintas, S., Si, L., Xin, Y. P. P., & Hord, C. (2009). Automatic detection of off-task behaviors in intelligent tutoring systems with machine learning techniques. *IEEE Transactions on Learning Technologies*, *3*(3), 228-236.

[7] Cuschieri, T., Khaled, R., Farrugia, V. E., Martinez, H. P., & Yannakakis, G. N. (2014, September). The iLearnRW game: support for students with Dyslexia in class and at home. In *2014 6th international conference on games and virtual worlds for serious applications (VS-GAMES)* (pp. 1-2). IEEE.

[8] Martins, V. F., Lima, T., Sampaio, P. N., & de Paiva, M. (2016, November). Mobile application to support dyslexia diagnostic and reading practice. In *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)* (pp. 1-6). IEEE.

[9] Rathee, N. (2016, March). A novel approach for lip reading based on neural network. In *2016 International Conference on Computational Techniques in Information and Communication Technologies (ICCTICT)* (pp. 421-426). IEEE.

[10] Asvestopoulou, T., Manousaki, V., Psistakis, A., Smyrnakis, I., Andreadakis, V., Aslanides, I. M., & Papadopouli, M. (2019). Dyslexml: Screening tool for dyslexia using machine learning. *arXiv preprint arXiv:1903.06274*.

[11] Khakhar, J., & Madhvanath, S. (2010, November). Jollymate: Assistive technology for young children with dyslexia. In *2010 12th International Conference on Frontiers in Handwriting Recognition* (pp. 576-580). IEEE.

[12] Pedler, J. (2007). *Computer correction of real-word spelling errors in dyslexic text* (Doctoral dissertation, University of London).

[13] Lin, C. Y., & Chai, H. C. (2014, August). Using an e-talk pen to promote phonological awareness on communication training. In *2014 9th International Conference on Computer Science & Education* (pp. 298-302). IEEE

[14] Atkar, G., & Priyadarshini, J. (2020). Advanced machine learning techniques to assist dyslexic children for easy readability. *International Journal of Scientific & Technology Research,(IJSTR), ISSN*, 2277-8616.

[15] Taileb, M., Al-Saggaf, R., Al-Ghamdi, A., Al-Zebaidi, M., & Al-Sahafi, S. (2013). YUSR: Speech recognition software for dyslexics. In *Design, User Experience, and Usability. Health, Learning, Playing, Cultural, and Cross-Cultural User Experience: Second International Conference, DUXU 2013, Held as Part of HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013, Proceedings, Part II 2* (pp. 296-303). SpringerBerlinHeidelberg.

[16] Rello, L., Bayarri, C., Otal, Y., & Pielot, M. (2014, October). A computer-based method to improve the spelling of children with dyslexia. In *Proceedings of the 16th international ACM SIGACCESS conference onComputers&accessibility* (pp.153-160)