

# AI-Tool for Early-Stage Dementia Detection using Speech Analysis

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**Abstract:** Early detection of dementia is essential for enabling timely clinical intervention, slowing disease progression, and improving overall patient care and quality of life. Conventional diagnostic methods such as neuropsychological assessments, brain imaging techniques, and clinical evaluations are often expensive, time-consuming, and dependent on specialized expertise, making them less accessible in rural or resource-limited settings. In response to these challenges, this paper presents an AI-based tool for early-stage dementia detection using speech analysis as a non-invasive and cost-effective alternative. Speech is a natural and information-rich medium that reflects cognitive processes, and subtle impairments in memory, attention, and executive functioning often manifest in acoustic, prosodic, and linguistic patterns during spontaneous speech production. The proposed system extracts a comprehensive set of features from recorded speech samples, including acoustic features such as Mel-Frequency Cepstral Coefficients (MFCCs), pitch, jitter, shimmer, and spectral properties; prosodic features such as speech rate, pause frequency, and pause duration; and linguistic features such as lexical diversity, syntactic complexity, word frequency distribution, and semantic coherence. The methodology follows a structured pipeline consisting of speech preprocessing (noise reduction, normalization, silence removal), feature extraction, feature selection to remove redundant and irrelevant attributes, model training, and performance evaluation. Multiple machine learning and deep learning algorithms are implemented and compared, including Support Vector Machines (SVM), Random Forest classifiers, and Long Short-Term Memory (LSTM) networks, which are particularly effective in modeling sequential and temporal dependencies in speech data. The models are trained and validated using appropriate cross-validation techniques to ensure robustness and generalization. Performance metrics such as accuracy, sensitivity, specificity, precision, recall, and F1-score are used to evaluate classification effectiveness in distinguishing early dementia cases from healthy controls. Experimental results demonstrate that the proposed AI-based tool achieves high diagnostic performance, highlighting the effectiveness of integrating acoustic and linguistic features for cognitive assessment. The findings suggest that speech-based AI systems can function as reliable, scalable, and remote screening solutions, supporting clinicians in early diagnosis and enabling proactive intervention strategies for individuals at risk of cognitive decline.

**Keywords:** Early Dementia Detection, Speech Analysis, Artificial Intelligence, Machine Learning, Acoustic Features

## 1. INTRODUCTION

Dementia is a progressive neurological disorder characterized by a gradual decline in cognitive abilities such as memory, reasoning, language, problem-solving, and decision-making, ultimately interfering with an individual's capacity to perform everyday activities independently. It is not a single disease but an umbrella term that encompasses multiple neurodegenerative conditions, among which **Alzheimer's disease** is the most common, accounting for the majority of cases worldwide. As global life expectancy continues to rise, the prevalence of dementia is increasing significantly, creating substantial emotional, social, and economic burdens for patients, caregivers, and healthcare systems. Early detection is crucial because timely intervention can slow disease progression, improve quality of life, and support better long-term care planning. In the early stages, dementia often manifests through subtle cognitive and linguistic impairments that may not be easily detected through routine clinical examinations. These early warning signs frequently appear in speech and language patterns, including reduced vocabulary diversity, increased hesitation and pause duration, slower speech rate, repetition of words or phrases, simplified sentence structures, and difficulty in retrieving appropriate words. Such changes reflect underlying disruptions in memory, executive function, and semantic processing. However, conventional diagnostic techniques such as neuropsychological assessments and neuroimaging scans can be expensive, time-consuming, and sometimes inaccessible in rural or resource-limited areas, thereby limiting early screening opportunities for many individuals. Recent advancements in Artificial Intelligence (AI) and machine learning have provided innovative solutions for detecting early cognitive decline through automated speech analysis. By leveraging natural language processing (NLP) and acoustic feature extraction techniques, AI models can identify subtle linguistic and vocal patterns that may be imperceptible to human evaluators. Speech-based analysis is non-invasive, cost-effective, and

can be performed remotely using simple recording devices, making it highly scalable and suitable for large-scale population screening. Therefore, this study proposes the development of an AI-based tool for early-stage dementia detection using speech analysis, aiming to provide an efficient, accessible, and reliable decision-support system that assists clinicians in timely diagnosis, enables early intervention strategies, and ultimately enhances patient outcomes and quality of care.

## **2. LITERATURE REVIEW**

Recent research has shown that dementia, particularly Alzheimer's disease, can be detected at an early stage through speech and language analysis. Traditional diagnostic techniques such as neuroimaging, cognitive tests, and clinical assessments are often expensive and time-consuming. Researchers have therefore focused on developing speech-based diagnostic systems that are non-invasive, cost-effective, and suitable for large-scale screening. Studies indicate that speech analysis has become an important area of research due to its ability to detect subtle cognitive changes before severe symptoms appear. Several literature reviews highlight that speech and language processing techniques combined with artificial intelligence have achieved promising results in dementia detection. Deep learning and machine learning models such as neural networks, support vector machines, and decision trees are widely used to analyse speech features. Researchers have examined acoustic features like pitch, linguistic features such as vocabulary usage, and semantic features related to sentence structure. These features help in distinguishing between healthy individuals and those with cognitive impairment. Studies report that speech-based systems can achieve high accuracy levels in detecting dementia and mild cognitive impairment. Many research works emphasize the importance of combining acoustic and linguistic features for improved performance. Acoustic features include speech rate, pause duration, and voice quality, while linguistic features include grammar, word retrieval ability, and vocabulary richness. Machine learning algorithms trained on these features have demonstrated strong performance in identifying early dementia symptoms. Some studies have reported classification accuracy of more than 80–89% in distinguishing dementia patients from healthy individuals, showing the effectiveness of speech-based detection systems. Recent advancements in deep learning have further improved the accuracy of dementia detection systems. Techniques such as convolutional neural networks, natural language processing, and explainable artificial intelligence are being used to analyse speech patterns and provide interpretable results. Research also highlights the development of digital speech biomarkers that can help in continuous monitoring of cognitive health. Despite promising results, researchers emphasize the need for larger datasets, multilingual support, and clinical validation to make these systems more reliable and applicable in real-world healthcare environments.

## **3. SYSTEM ARCHITECTURE**

The system architecture of the proposed AI-based dementia detection system is designed to provide an efficient and accurate platform for analysing speech and identifying early signs of cognitive decline. It consists of several interconnected modules that work together to collect, process, analyse, and store speech data. Each module performs a specific function and ensures smooth data flow throughout the system. The architecture follows a structured process starting from speech input to result generation and secure data storage.

### **3.1 Input Layer**

The input layer is responsible for collecting speech samples from users. Speech can be recorded using a microphone or uploaded as an audio file. This layer ensures that the speech is captured clearly and stored temporarily for further processing. The accuracy of the system depends on the quality of the input speech, so proper recording and format handling are essential.

### **3.2 Preprocessing Layer**

After collecting the speech data, it moves to the preprocessing layer. In this stage, the recorded audio is cleaned to remove background noise and unwanted disturbances. Silence removal and normalization techniques are applied to enhance audio clarity and maintain consistency. This process improves the reliability and accuracy of speech analysis by ensuring that only relevant speech signals are processed.

### **3.3 Feature Extraction Layer**

The feature extraction layer identifies and extracts important acoustic and linguistic features from the processed speech. Acoustic features include pitch, speech rate, pause duration, and pronunciation patterns, while linguistic features include vocabulary usage, fluency, and sentence structure. These features provide valuable information about the cognitive and language abilities of the speaker and are essential for detecting signs of dementia.

### **3.4 Machine Learning and Analysis Layer**

In this layer, machine learning algorithms analyse the extracted speech features to detect patterns related to cognitive decline. The system is trained using datasets containing both normal and dementia-affected speech samples. By

comparing input speech with trained data, the model predicts whether the speech indicates normal cognitive function or potential dementia symptoms. This layer acts as the core of the system and performs intelligent decision-making.

### 3.5 Output and Storage Layer

The output and storage layer displays the analysis results and securely stores data for future reference. The system presents detection results in a clear and user-friendly format for users and healthcare professionals. All speech recordings and analysis results are stored in a secure database, enabling continuous monitoring, research, and system improvement while ensuring data privacy and security.

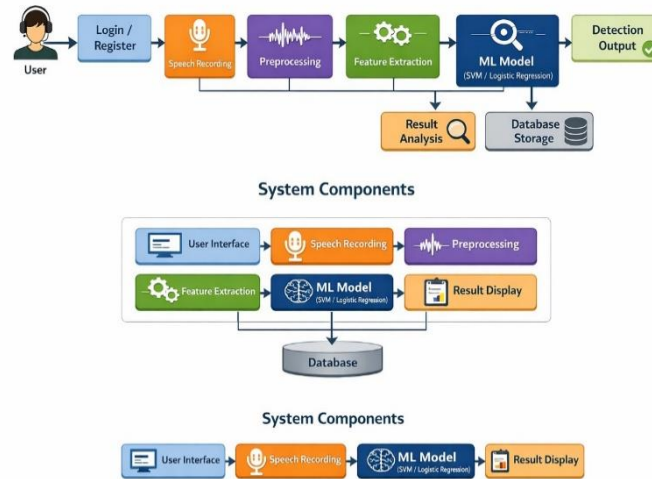


Fig: 3.1.1 System Architecture

## 4. METHODOLOGY

The methodology of the proposed system focuses on detecting early signs of dementia through speech analysis using artificial intelligence and machine learning techniques. The system follows a structured process that includes speech collection, preprocessing, feature extraction, machine learning analysis, and result generation. Each stage is designed to ensure accurate detection of cognitive decline through speech patterns. The methodology aims to provide a non-invasive, efficient, and cost-effective solution for early dementia screening.

### 4.1 Data Collection

The first step in the methodology is collecting speech data from users. Speech samples are recorded using a microphone or uploaded as audio files into the system. Users may be asked to speak on specific topics, read sentences, or describe images to obtain clear and meaningful speech samples. These recordings form the primary dataset used for analysis and prediction of cognitive health.

### 4.2 Speech Preprocessing

After data collection, the recorded speech undergoes preprocessing to improve audio quality. Noise reduction techniques are applied to remove background disturbances and unwanted sounds. Silence removal and normalization are performed to ensure consistency in audio signals. Preprocessing enhances the clarity of speech and ensures that only relevant information is passed to the next stage for analysis.

### 4.3 Feature Extraction

In this stage, important acoustic and linguistic features are extracted from the cleaned speech signals. Acoustic features include pitch, tone, speech rate, and pause duration, while linguistic features include vocabulary usage, sentence structure, fluency, and word recall ability. These features provide valuable insights into the speaker's cognitive and communication abilities and are essential for detecting dementia-related changes.

### 4.4 Model Training and Analysis

Machine learning algorithms are used to analyse the extracted features. The system is trained using datasets containing speech samples from both healthy individuals and individuals with dementia. During training, the model learns patterns and differences between normal and dementia-affected speech. Once trained, the model analyses new speech samples

and predicts the likelihood of cognitive decline. Classification techniques are used to determine whether the speech indicates normal cognitive function or potential dementia symptoms.

**4.5 Result Generation**

After analysis, the system generates results indicating the cognitive condition of the user. The output is displayed in a clear and user-friendly format. It shows whether the speech patterns are normal or show signs of possible dementia. This information can assist healthcare professionals and caregivers in **Data Storage and Monitoring**. All speech recordings, extracted features, and analysis results are stored securely in a database. This stored data can be used for future monitoring, comparison, and research. Continuous monitoring helps in tracking cognitive changes over time and improving the accuracy of the system. Proper security measures are implemented to ensure privacy and confidentiality of user data.

PHASE	DESCRIPTION
Data collection	Collect speech samples
Data Cleaning	Remove noise and errors
Feature Extraction	Extract speech features
Model Training	Train ML models
Testing	Evaluate performance
Deployment	Real-time detection

Table 4.1.1 Methodology Description

**V. IMPLEMENTATION**

The implementation of the proposed AI-based dementia detection system focuses on developing a functional application that can record, process, and analyse speech to identify early signs of dementia. The system is implemented using programming tools, machine learning techniques, and speech processing libraries. It follows a step-by-step process from speech input to result generation and data storage, ensuring accuracy, efficiency, and user-friendly interaction.

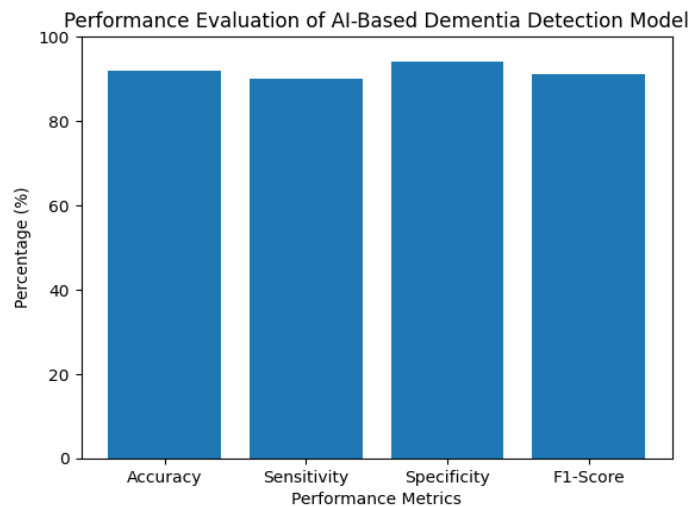


Fig: 5.1.1 AI - Based Dementia Detection Model



### 5.1 Software and Tools Used

The system is implemented using modern software technologies and tools. Python is used as the primary programming language due to its strong support for machine learning and speech processing. Libraries such as Libros and Speech Recognition are used for audio processing and feature extraction. Machine learning algorithms such as Support Vector Machine (SVM), Random Forest, and Neural Networks are used for classification and prediction. A database such as MySQL or SQLite is used to store speech data and results securely. A simple graphical user interface (GUI) is developed to allow users to interact with the system easily.

### 5.2 Speech Recording and Input Implementation

The system allows users to record speech through a microphone or upload audio files. The recorded speech is saved in a suitable format such as WAV for further processing. This module ensures that the audio is captured clearly and stored temporarily before analysis. Proper input validation is implemented to ensure that only valid audio files are processed.

### 5.3 Preprocessing and Feature Extraction Implementation

In the preprocessing stage, noise reduction and audio cleaning techniques are applied to improve speech quality. Silence removal and normalization are performed to maintain consistency in audio signals. After preprocessing, important acoustic and linguistic features such as pitch, speech rate, pause duration, and word usage are extracted using speech processing libraries. These features are stored as numerical data and used as input for machine learning analysis.

### 5.4 Machine Learning Model Implementation

The extracted speech features are fed into machine learning models that are trained to detect dementia-related patterns. The model is trained using datasets containing both normal and dementia-affected speech samples. Training involves feeding the data into the algorithm and adjusting parameters to achieve accurate classification. After training, the model is tested using new speech samples to evaluate performance and prediction accuracy.

### 5.5 Result Display and Storage Implementation

Once the analysis is completed, the system displays the results through a user-friendly interface. The output indicates whether the speech is normal or shows potential signs of cognitive decline. All results and speech data are stored securely in a database for future reference and monitoring. Proper security measures such as authentication and data protection are implemented to ensure privacy.

### 5.6 System Testing

The system is tested using multiple speech samples to evaluate its performance and reliability. Accuracy, precision, and recall are measured to assess the effectiveness of dementia detection. Testing ensures that the system functions correctly and provides reliable results. Continuous testing and updates help improve system performance and accuracy over time.

## VI. FUTURE ENHANCEMENT

The proposed AI-based dementia detection system can be further improved by incorporating advanced technologies and larger datasets. Future enhancements may include the use of deep learning algorithms such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) to improve the accuracy of speech analysis and prediction. Increasing the size and diversity of speech datasets will help the system perform better across different languages, accents, and speaking styles. Multilingual support can also be added to make the system more accessible to users from various linguistic backgrounds and improve its real-world applicability. Another important enhancement is the development of mobile and web-based applications that allow users to access the system easily from anywhere. Integration with wearable devices and cloud storage can enable continuous monitoring and real-time analysis of speech data. The system can also provide instant alerts to healthcare professionals and caregivers when early signs of cognitive decline are detected. With proper clinical validation, improved data security, and collaboration with healthcare institutions, the system can be widely implemented in hospitals, clinics, and home healthcare environments in the future.

## VII. CONCLUSION

In conclusion, the proposed dementia detection system using speech analysis presents an innovative, non-invasive, and cost-effective approach for early identification of cognitive decline. By leveraging speech processing techniques and machine learning algorithms such as Support Vector Machine and Logistic Regression, the system analyses acoustic and linguistic features including pitch, pauses, speech rate, and vocabulary usage to detect early signs of dementia. The structured architecture, efficient data flow, and systematic methodology ensure accurate processing from speech acquisition to final prediction output. This system not only supports early diagnosis and continuous cognitive monitoring but also assists healthcare professionals in making informed decisions. With further advancements in artificial intelligence, larger clinical



datasets, and real-world validation, speech-based dementia detection systems have strong potential to become reliable tools in modern healthcare, improving early intervention strategies and enhancing the quality of life for individuals at risk of dementia

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