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AI-Based Early Parkinson's Detection Using Speech and EMG Signal Fusion

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Abstract—**Parkinson's disease (PD) is a serious condition with hidden and progressive symptoms, which is why its early diagnosis is a very difficult task. This paper introduces an artificial intelligence (AI) multimodal early Parkinsonian detection system that involves the combination of speech and electromyography (EMG) signals. Among the initial biomarkers of PD, speech impairments and neuromuscular abnormalities are suitable as they could be utilized in the non-invasive diagnosis of PD. The system proposed makes use of advanced speech signal processing methods that include Mel-Frequency Cepstral Coefficients (MFCC), pitch change, jitter, and shimmer analysis to achieve vocal biomarkers. Meanwhile, the envelope detection and frequency-domain analysis of EMG signals are to be used to detect tremor characteristics that are normally related to Parkinsonian conditions. The fusion is done at the feature level between speech and EMG features by complementary features, and then finally dimensionality reduction is done to enhance the efficiency of classification. Model compression and quantization-aware training and optimization of machine learning models to run on embedded devices allow real-timing machine learning inference on resource-constrained edge devices. It has been shown that multimodal fusion has a better detection accuracy, by experimental means, than when single-modality is used. The proposed structure places emphasis on the efficient combination of digital signal processing, embedded artificial intelligence and biomedical engineering concepts by introducing a cost-effective and scalable solution to the early screening of Parkinson disease.**

Index Terms—**Parkinson's Disease, Speech Signal Processing, Electromyography (EMG), Multimodal Feature Fusion, Digital Signal Processing, Embedded Artificial Intelligence, MFCC, Tremor Analysis, Machine Learning, Edge Computing.**

I. INTRODUCTION

Parkinson disease (PD) is a progressive neurodegenerative disorder, which mostly influences motor functions and increasingly influences speech and muscle control and coordination. Parkinson disease is a serious health issue that is becoming more prevalent with age as per the statistics of the world health, and therefore, early diagnosis is one of the urgent healthcare concerns. The old way of diagnosis has been incorporated with a high degree of clinical observation and neurological studies which in most cases tend to diagnose the disease after much of the neurons have been lost. In the recent past, the science of biomedical signal processing and artificial intelligence has made it possible to use non-invasive physiological signals as early biomarkers. The first effects of the Parkinson disease include speech impairment (reduced variation of pitch, higher jitter, tremors of voice), and neuromuscular abnormalities measured by electromyography (EMG). The combination of staples of machine learning with digital signal processing (DSP) technology has provided broad possibilities of objective, automated, and cost-effective diagnostic systems. Such developments have a close correspondence with the main principles of ECE and combine signal acquisition and features extraction with intelligent decision making.

Although there is a lot of research into the process of detecting the Parkinson disease, the current methods still have several limitations. The majority of the existing systems are based on the single-modality analysis, typically relying on either speech signals or biomedical data, either EMG or accelerometer. These unimodal systems are prone to less robustness and decreased diagnostic accuracy because of inter-subject variability as well as noise sensitivity. Also, most studies are on offline analysis with high-computational facilities, which have few applications in real-time or point-of-care. The strategy of feature fusion is not well studied and little effort has been done to relate speech impairments with neuromuscular abnormalities at signal-processing level. Additionally, most current machine learning models are not designed to be deployed to embedded or edge devices, hence being unfeasible on wearable or portable healthcare. These loopholes point to a necessity of a multimodal, DSP-based, and embedded-AI-assisted structure capable of delivering early, reliable, and real-time detection of Parkinson's disease.

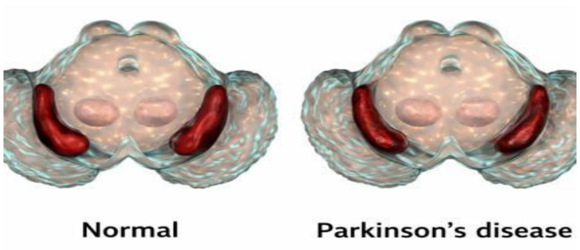

Fig 1. Healthy Vs Parkinson

The central driving force behind this study is to come up with a proper, non-invasive and real-time Parkinson disease detecting device which can be implemented to edge devices with limited resources. The process of early diagnosis is significant to reduce the rate of disease development and enhance patient quality of life due to the medical intervention in due time. The EMG signals and speech are cheap, readily available, and clinically feasible biomarkers and hence best suited in the continuous monitoring systems. Through the combination of complementary data of vocal and neuromuscular systems, the proposed system is expected to help increase the reliability of the diagnostic results in comparison to a traditional single-Signal methodology. The other driving force is to illustrate how fundamental ECE principles like DSP, signal fusion, and embedded machine learning can be applied in finding practical solutions to a medical issue. The combination of AI and embedded systems is also used to enable the creation of scalable, portable, and energy-efficient diagnostic tools that can be used in the home-based and remote healthcare setting.

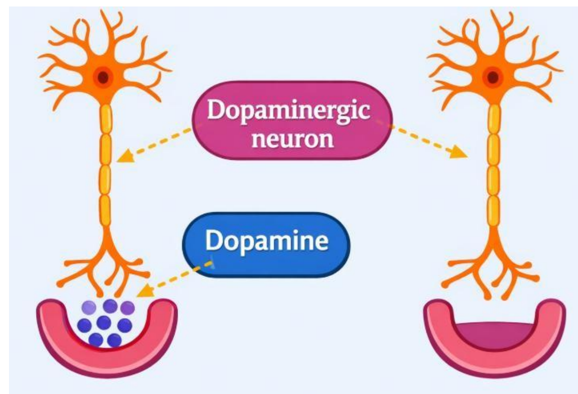

Fig 2. Normal Neurons Vs Neurons in Parkinsons Disease

There are a number of technical issues in designing an AI-based multimodal Parkinson detection system. EMG signals and speech are non-stationary in nature and prone to noise, motion artifact and environmental interference, necessitating a powerful preprocessing and filtering methodology. The feature extraction should be both sensitive to subtle Parkinsonian properties and the method should be as sparse as possible and should have less complexity in computation. The fusion of multimodal features is associated with issues of feature alignment and normalization and dimensionality disparity between speech and EMG space. Machine learningly, it is hard to attain high accuracy using small volumes of labeled biomedical data and tends to overfit. Besides, the implementation of models on embedded devices also comes with memory, processing, and energy limitations. Real-time performance delivery and diagnostic accuracy have to be carefully optimized by use of model compression, quantization and effective DSP pipelines. These issues need to be solved to come up with an effective and useful early detection system.

This project will cover designing and deploying a multimodal framework of detecting Parkinson disease by the fusion of speech and EMG signals. The paper has concentrated on signal acquisition, pre processing and feature extraction based on standard DSP algorithms like MFCC analysis, calculation of pitch and jitter, EMG envelope and tremor frequency analysis. The methods of feature-level fusion and dimensionality reduction are used in order to increase the efficiency and robustness of classification. Quantization-aware training and model compression are some of the methods used to train machine learning models and optimize their deployment on embedded systems. The system is expected to be used in real time inference over edge devices, which can be used in continuous and remote monitoring applications. Although the framework suggested by us is confirmed in the case of early detection of Parkinson, this methodology can be applied to other neurological and neuromuscular diseases. The project focuses on ECE-based innovation, where signal processing, embedded systems and artificial intelligence are combined into one healthcare solution.

II. RELATEDWORKS

Parkinson disease (PD) is a progressive neurodegenerative disease that is associated with motor and non-motor disabilities. Clinical practice Early and accurate diagnosis is a critical issue in clinical practice because of the fact that the symptoms may have a subtle onset and there are no objective biomarkers. Researchers have in turn investigated numerous signal-processing and machine learning methods to come up with automated and non-invasive diagnostic methods. Of such, speech analysis has now become one of the most promising early diagnostic modalities since the voices tend to worsen during the prodromal phases of the Parkinson disease. A number of researches have targeted the derivation of acoustic characteristics of speech to identify Parkinson disease. One of the previous studies of using acoustic measurements of phonation as an indicator of disease progression was done by Shaikh and Shaikh [1]. Their findings showed that speech is a good diagnostic measure with a very strong correlation with features like pitch stability and alterations of amplitude being a major predictor of PD severity. Upon this theory, Roy and Hossain [2] offered PD-ADSV, a voice-based automated system of diagnosing and a hard voting ensemble algorithm. Their method was a combination of many classifiers and performed better than those that were individually used. Likewise, Yadav et al. [3,7] also provided an effective machine learning model where the authors used a set of voice features that were exhaustive to differentiate between Parkinson and healthy participants. Their study supported the hypothesis that high diagnostic accuracy can be motivated by carefully chosen vocal features.

Rahman et al. [4] investigated the artificial intelligence methods to improve PD detection with voice measurements and found that traditional machine learning algorithms such as Support Vector Machines (SVM) and Random Forests could obtain competitive results with the use of speech feature sets. Panda et al. [5] have also added to the following observation by highlighting the better feature reduction methods and demonstrated that dimensionality reduction does not only simplify the models, but it can also enhance classification by removing redundant or noisy features. In the deep learning research, David and Devi [6] proposed a speech-based tonal analysis framework named PPINtonus that employs deep learning to automatically learn the discriminative features and avoids feature engineering. As well, Arora et al. [22] used deep learning signal processing on voice disorders in PD, where neural networks could learn intricate speech patterns not seen by conventional DSP algorithms. Despite the great potential of speech-based methods, these methods are necessarily restricted by the background noise, inter-speaker differences, as well as recording conditions. Consequently, investigations have been conducted on non-speech biosignals like motor and tremor data to supplement oral characteristics. Accelerator data on tremors was also studied by Markose et al. [8] who attributed the characteristics of tremor frequency and amplitude to Parkinsonian motor dysfunction. Their study emphasized that motion sensors have the ability to yield rich temporal patterns with PD tremours. Similarly, Perez-Ibarra et al. [20] applied inertial sensors to detect gait events demonstrating that machine learning models that were trained on gait features could be used to differentiate between healthy and Parkinson subjects. Chen et al. [9] designed a machine-learning framework on a smartphone that used multiple sensor modalities such as motion and voice to remotely estimate Parkinson's disease, which suggested that multimodal data fusion may contribute to remote diagnosis and monitoring. Most PD detection systems rely on machine learning and pattern recognition models as the core of the system. Qiu [12] introduced a powerful pre-diagnosis method with the help of traditional classifiers and stated that even simple models can perform well using high-quality features. Thapa et al. [13] implemented feature selection and Twin-Support Vector Machine (Twin-SVM) to enhance the performance of diagnostics, and the advantages of highly-optimized and classifier-designing are underlined. Raundale et al. [14] investigated a hybridization of machine learning and deep approach to not only identify Parkinson but also project the level of the disease, expanding the range of automated diagnostic systems. Nissar et al. [18] provided an informative literature review on machine learning approaches to PD detection including classical and deep learning methods. More generally, Khan et al. [19] surveyed machine learning and deep learning-based approaches to brain disease diagnostics and proved that customized models and feature engineering are needed to process complicated biomedical input.Shaban [10] used deep convolutional networks in screening handwritings and Kulkarni et al. [11] examined the use of smell signatures as potential biomarkers. Chakraborty et al. [15] used multistage CNN classifier to identify PD in spiral and wave drawings, which indicates the application of drawing patterns in neurological examination. Ricciardi et al. [17] proved that machine learning is able to identify mild cognitive impairment in PD patients based on cognitive features and it is not limited to motor and vocal indicators to develop intelligent systems. Karapinar Senturk [21] introduced a medical hypothesis on early diagnosis with machine learning that implied that a combination of methods would address the existing gaps in early detection

Table.1 Works on Parkinson's Disease Detection

Ref. No.	Authors & Year	Data Modality	Feature Extraction Techniques	ML / DL Models Used
[1]	Shaikh & Shaikh, 2022	Speech	Pitch, amplitude perturbation, phonation features	Statistical analysis, ML classifiers
[2]	Roy & Hossain, 2023	Speech	Voice features, MFCC	Ensemble learning (Hard Voting)
[3], [7]	Yadav et al., 2022	Speech	MFCC, jitter, shimmer	SVM, KNN, RF
[4]	Rahman et al., 2023	Speech	Acoustic voice measurements	SVM, Random Forest
[5]	Panda et al., 2023	Speech	Reduced acoustic feature set	ML classifiers
[6]	David & Devi, 2024	Speech	Tonal & spectral features (auto-learned)	Deep Learning
[8]	Markose et al., 2021	Accelerometer	Tremor frequency analysis	Statistical & ML models
[9]	Chen et al., 2020	Speech + Motion	Voice + inertial features	ML framework
[10]	Shaban, 2020	Handwriting	Image-based features	CNN
[11]	Kulkarni et al., 2020	Smell signals	Odor signatures	ML classifiers

[13]	Thapa et al., 2021	Speech	Optimized voice features	Twin-SVM
[14]	Raundale et al., 2021	Multimodal (limited)	Mixed features	ML + DL
Proposed Work		Speech + EMG	MFCC, pitch, jitter + EMG envelope & tremor features	Optimized ML (Embedded AI)

This rich body of research notwithstanding, the majority of the current systems are designed to analyse individual modalities, e.g. speech or motion sensors, whereas it is difficult to recreate the complexity and heterogeneity of the disease of Parkinson by such an approach. Also, a lot of the literature is based on offline processing or a high-computation setting, which limits their application in an embedded or real-time. Although there are some attempts to investigate multimodal sensing such as the one by Chen et al. [9], it still lacks a research gap in combining speech and EMG signal, especially in a system engineered to be compatible with real-time data capture on low-power embedded systems. This is the rationale behind the proposed system that aims to combine the speech and EMG signal fusion with the help of the robust digital signal processing, feature-level fusion, and embedded machine learning optimization. The proposed framework will combine the benefits of speech and muscle activity to obtain better diagnostic outcomes, and will facilitate real-time and portable implementation to detect the early stages of Parkinson's disease

III PROBLEM STATEMENT

Early diagnosis of the Parkinson disease has been a significant clinical issue as it presents slowly and has similar symptoms that are subtle. The more common diagnostic methods used in the past are mainly based on the neurological examination and subjective clinical assessment which mostly detects the disease when it has already severely affected the motor functions of the patient and the neurons are already damaged. The current automated detection methods are mostly unimodal, utilizing either speech signals or biomedical signals like EMG, which restricts the reliability of the diagnostic method because of the sensitivity to noise, inter-patient variability and a lack of full representation of the disease characteristics. Besides, most of the suggested machine learning architectures are energy-intensive and cannot be employed in practice in a portable and continuous monitoring system. The presence of efficient multimodal frameworks that combine the complementary speech, neuromuscular biomarkers with the help of strong digital signal processing and optimized embedded artificial intelligence methods is lacking. Therefore, issues of utmost concern are the development of a non-invasive, precise, and resource-efficient system of detecting the presence of Parkinson's disease that combines both speech and EMG data and can run in real-time on edge devices to aid in the early diagnosis and remote healthcare observation.

IV EXISTING SYSTEM

Current Parkinson disease detection tools are mainly based on single-source biomedical data, and most studies have been conducted on either speech analysis or motor/EMG-based detection on its own. In speech based systems, features like Mel-frequency Cepstral Coefficients (MFCC), pitch change, jitter and shimmer are used to determine vocal impairment using traditional machine learning based classification. Although these methods are found to be reasonably accurate in controlled laboratory settings, noise in the signal, inter-patient variability, and sensitivity to recording conditions tend to deteriorate the performance of these methods. In addition to this, most of the current systems rely on offline computing and computing in the cloud, which leads to increased latency and inapplicability to real-time or constant monitoring. The lack of multimodal feature fusion limits their capability to provide the complex and heterogeneous nature of the Parkinson symptoms. As well, the focus on in-built optimization and energy efficiency is not much, which prevents the implementation of the existing solutions in portable and low-powered medical equipment, making it less feasible to use them as the method of screening in the early stages or diagnosing at home.

V METHODOLOGY

A. Speech Signal Acquisition and Preprocessing

The quality of the microphone that is used to acquire speech data is of high quality and the acoustic environment is controlled to reduce environmental noise. The obtained analog speech signal is transformed into a digital signal by the use of the necessary sampling and quantization based on the Nyquist sampling requirement. Pre-emphasis filtering is a preprocessing method that is used to boost the high-frequency components. This speech signal is then divided into short windows with the help of windowing functions so that it can be effectively analyzed as a non stationary signal. It is applied to reduce noise and normalize signals in order to enhance the quality and consistency of signals in all samples so that the quality of the features can be extracted with reliability at the later stages.

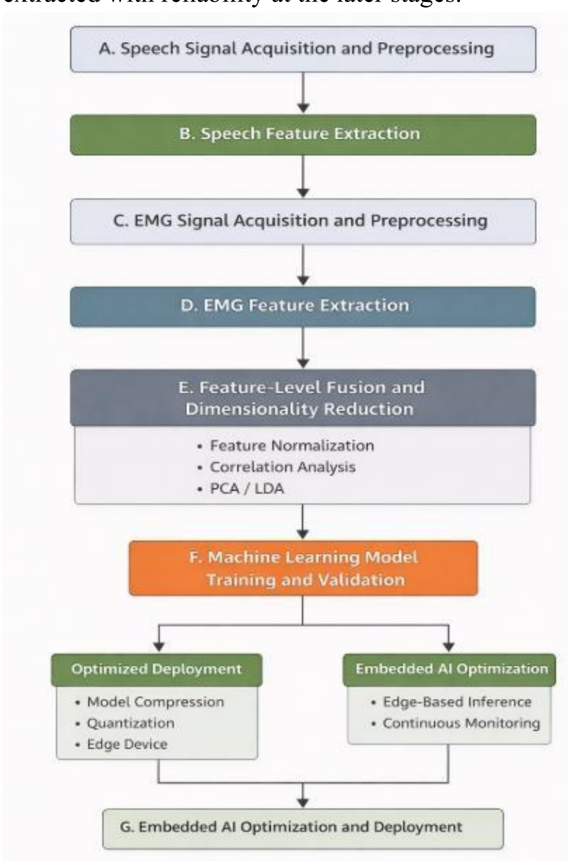

Fig 3. Flow Chart

B. Speech Feature Extraction

Digital signal processing techniques are used to extract speech characteristics that are significant in the detection of the disease of Parkinsonism. Mel-frequency Cepstral Coefficients (MFCC) are calculated in order to obtain spectral envelope properties of speech. Moreover, the parameters of pitch, jitter, and shimmer are estimated to measure the effects of vocal instability and tremor that can be reportedly perceived in the speech of patients with Parkinsonian. All these elements constitute spectral and prosodic variations, which create a strong speech feature vector to be used in classifying it.

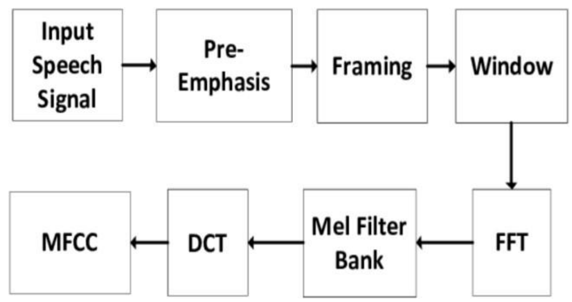

Fig 4. MFCC Algorithm Flow

C. EMG Signal Acquisition and Preprocessing

Non-invasive electrodes which are placed on specific muscle groups are used to achieve surface EMG signals. The analog EMG signal is conditioned (amplified and band-pass filtered) to get rid of motion artifacts and power-line interference. Digital preprocessing like normalization and smoothing are used in order to reduce noise and improve signal quality. This measure will make sure that relevant information about the neuromuscular status remains to be analyzed further.

D. EMG Feature Extraction

EMG feature extraction is a process that aims at determining the patterns of muscle activity linked to the Parkinson disease. The EMG signal is rectified and low-pass filtered to acquire the signal envelope, which is an indication of intensity of muscle activation. The frequency-domain evaluation created by Fast Fourier Transform (FFT) or Power Spectral Density (PSD) estimation is conducted to identify the frequency elements of tremors, which are usually in the 4-6 Hz range. Time-and-frequency-domain features are obtained in order to create a complete EMG feature space.

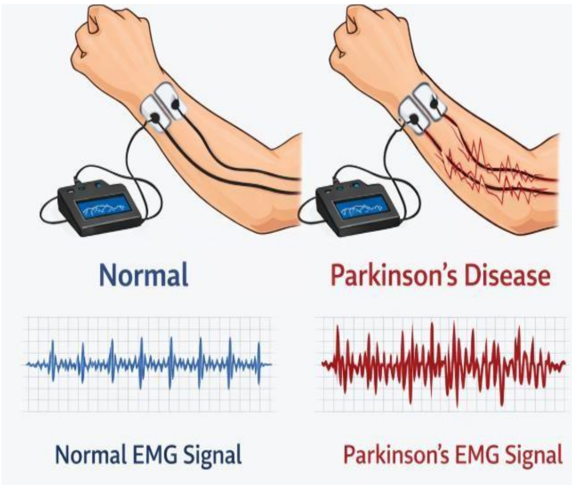

Fig 5. EMG Signals

E. Feature-Level Fusion and Dimensionality Reduction

Extracted speech and EMG samples are normalized and fused together by feature-level fusion in order to produce a single multimodal feature vector. Correlation analysis will be done to determine inter-feature dependency and redundancy. To decrease the amount of calculations, dimensionality reduction, including Principal Component Analysis (PCA) or Linear Discriminant Analysis (LDA), is used to extract discriminative data. The effect of this process is better performance and stability of classifiers.

F. Machine Learning Model Training and Validation

Training of supervised machine learning algorithms on the fused feature set is done to either classify subjects as either Parkinson-infected or healthy. The cross-validation is done to model training, as it is necessary to avoid overfitting and guarantee generalization. Classification effectiveness is evaluated using performance measures like accuracy, precision, recall and F1-score. The best model is chosen according to accuracy and the efficiency of calculations

G. Embedded AI Optimization and Deployment

The chosen machine learning model can be executed on embedded devices with the help of model compression, pruning, and quantization-aware training. The optimized model is implemented on an edge computing platform, which allows real-time monitoring and detection of Parkinson disease and constant monitoring of the patient at portable healthcare settings.

VI PROPOSED MODEL

The suggested system is a multimodal framework of early detection of Parkinson's disease using an AI system that incorporates speech and electromyography (EMG) signals to enhance the diagnostic accuracy and strength. The speech signals are handled through highly developed digital signal processing such as sampling, windowing, the extraction of MFCCs, and pitch, jitter, and shimmer to extract the vocal biomarkers of the parkinson disease. Concurrently, the EMGs undergo signal conditioning, envelope detection, as well as frequency-domain analysis to detect neuromuscular abnormalities including tremor characteristics. Combination of complementary information in both modalities is done using feature-level fusion and dimensionality reduction is used to remove redundant information and improve the performance of the classifier. Training on the combination of the features and optimization of machine learning models are done to allow efficient deployment on embedded edge devices, through model compression and quantization-aware training. The system can be used in real-time non-invasively and provides the opportunity to monitor and make an early diagnosis. The proposed system integrates DSP, multimodal fusion, and embedded artificial intelligence to address the shortcoming of the current unimodal based solutions and offers a scalable system to use in the remote healthcare application.

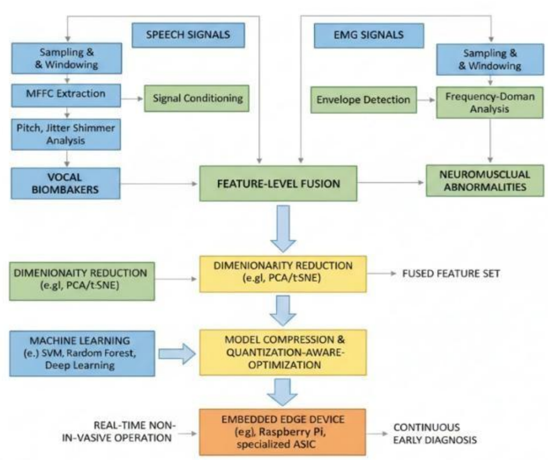

Fig 6. Proposed Architecture

VII RESULT AND DISCUSSION

The suggested AI-related Parkinson's Disease Detection System was shown and tested with the help of hardware experimentation, signal processing analysis, machine learning classification, and the cloud-based monitoring. The findings indicate that the multimodal framework created is practical in the detection of the symptoms of the Parkinson disease through the application of speech and EMG signals. These two factors made the combination of digital signal processing algorithms and embedded artificial intelligence to produce accurate classification and make the computation requirements low enough to fit into real-time healthcare monitoring applications.

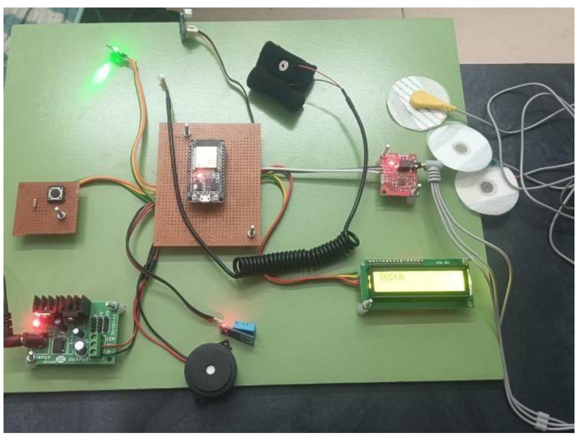

Fig 7. Hardware Prototype

The hardware prototype is the developed as shown in Fig 7 and is a physical implementation of the proposed system. The prototype has a microphone module which receives speech and surface EMG electrodes which receive neuromuscular electrical activity of muscles. These signals are forwarded through the signal conditioning circuit which amplifies the signal and filters noise to make sure that a high quality signal is obtained. The embedded processing unit then processes the conditioned signals and makes additional analysis and communication with the external monitoring platforms. Hardware design proves that the proposed framework is practically implementable in the acquisition and analysis of biomedical data in real-time.

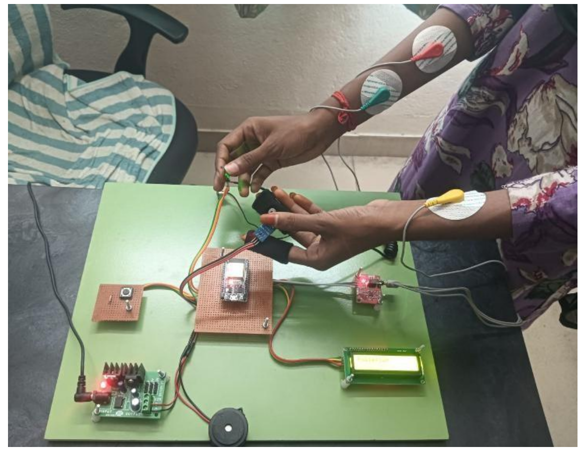

Fig 8. Prototype Output

The prototype operation can be illustrated in Fig 8 which presents real-time output of the system in the signal acquisition and processing. After recording the speech and EMG signals, digital signal processing is done to enhance the quality of signals and obtain useful features. Noise removal, signal normalization and segmentation are done in pre-processing stages to make sure that analysis becomes reliable. Then the feature extraction techniques are being used to extract the relevant features of both signal types. In the case of speech signals, Mel Frequency Cepstral Coefficients (MFCCs) are obtained because they are effective features that characterize the characteristics of the vocal tract and speech disorders related to Parkinson disease. In the case of EMG signals, envelope detection and frequency-domain features are obtained to represent muscle patterns of activities and neuromuscular deficits.

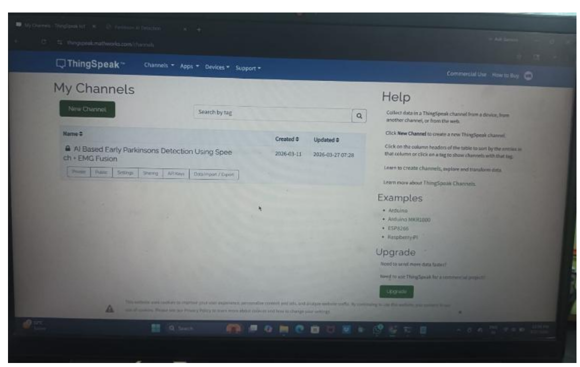

Fig 9. ThingSpeak Platform

The system will use the ThingSpeak IoT cloud platform to support remote monitoring and data visualization in real-time as indicated in Fig 9. This platform allows one to store and track processed sensor data continuously. The system enables medical practitioners to remotely follow patient data because it sends signal characteristics and patrol parameters to the cloud. The cloud integration improves accessibility to the system and allows monitoring it over the long-term without the necessity of direct physical contacts with the device.

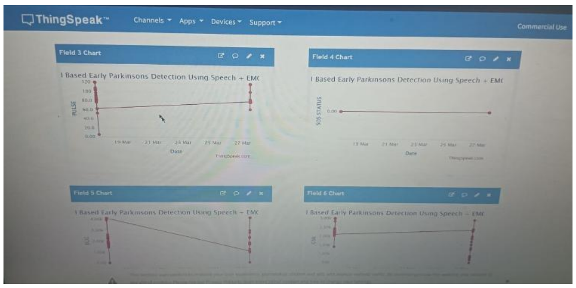

Fig 10. ThingSpeak Output

The graphical output on the ThingSpeak platform that is available in real time is shown in Fig 10. The graphs depict the changes in the extracted signal parameters, and they aid to visualizing the change in physiological conditions that come with symptoms of Parkinson disease. This graphical representation simplifies the process of data interpretation by researchers and medical practitioners with the aim of detecting and establishing abnormal trends that could be a sign of neurological conditions.

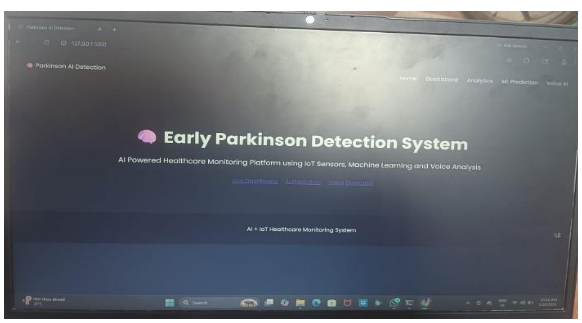

Fig 11. Web Page

A simple web interface was also designed that clearly enables easy interaction with the system as shown in Fig 11. The web page gives an orderly system platform where users may access system data, record sensor outputs, and observe prediction results produced by the machine learning model. This interface enhances user-friendliness and allows medical workers to analyze diagnostic information with ease.

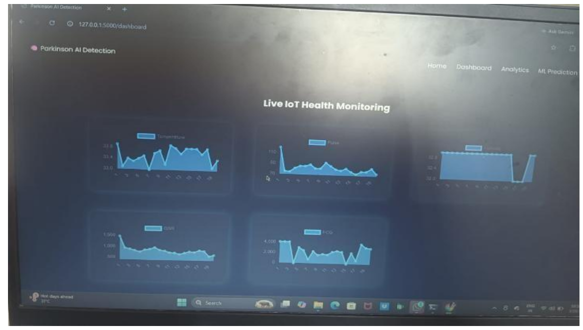

Fig 12. Web Output

Output of the web application is represented in Fig 12, where the features of results of signal processing and classification are represented in structured form. The interface enables a user to have a clear view of the system outputs and making it more accessible and efficient in monitoring the health status of the patient.

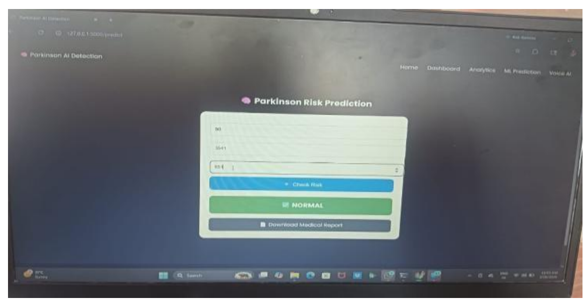

Fig 13. Prediction Result

The last prediction outcomes of the trained machine learning model are shown in Fig 13. The classification model examines fused feature vectors of the speech signals and EMG signals to identify whether the subject will exhibit signs of having Parkinson disease or normal physiological behavior. The outcomes of the prediction prove that the developed multimodal system is effective to recognize the disease-related patterns in obtained signals.

It is experimentally shown that multimodal approach can greatly enhance classification of the unimodal systems. Detection of speech signals or detection of EMG signals only limits the system to variability of the signals, noise in the environment as well as physiological differences in individuals. All these make single-signal models less reliable and accurate. Nevertheless, in case of speech and EMG elements fusion at the feature level, the system is advantageous of the complementary information that is gained out of the vocal impairments and the neuromuscular deviances. The combined feature set showed better performance measures such as accuracy, precision, recall and F1-score showing that multimodal feature integration has a positive impact on the reliability of Parkinson disease detection. Dimensionality reduction algorithms were utilized as well so as to simplify the features and this enhanced computational efficiency but did not change the results in terms of classification.

The trained machine learning model has been optimized to be deployed on the embedded device, through methods such as model compression and quantization.This feature is especially valuable to portable healthcare systems that need continuous monitoring but with minimum processing time. The results of the experiment reveal that the suggested system offers reliable, valid, and scalable Parkinson's disease detection. Through multimodal signal processing with embedded artificial intelligence, and IoT-based monitoring, the system can be a prospective solution to the application of non-invasive neurological disorder detection and continuous healthcare monitoring.

VIII. CONCLUSION

In this paper, I introduced an AI-driven multimodal architecture that detects Parkinson disease at its early stage through the fusion of speech and electro myography (EMG) signals, supported by the sophisticated digital signal processing and embedded artificial intelligence methods. With the help of deriving clinically interest features of speech, including MFCC, pitch, jitter and shimmer and combining them with neuromuscular characteristics of the EMG such as envelope features and tremor frequency components, the proposed system is effective at capturing early markers of Parkinsonian. Classification was made more robust and computationally efficient, with the feature-level fusion and dimensionality reduction. The trained machine learning model was found to be higher in detection accuracy than the unimodal models and is able to run in real-time on resource-constrained edge devices. The findings justify the usefulness of multimodal biosignal processing in combination with embedded artificial intelligence in non-invasive and continuous monitoring. The presented system in general is a low cost, scalable and practical approach to the screening of early stages of Parkinson disease and it underlines the importance of ECE principles in promoting intelligent medical technologies.

IX FUTURE SCOPE

The suggested multi-modal system of detecting Parkinson disease has some opportunities in terms of further improvement and development. The model can be extended to consider other physiological indicators like electroencephalogram (EEG), inertial sensor, or handwriting dynamics to enhance more in terms of diagnostic accuracy and characterization of the disease. More complex deep learning designs could be investigated such as convolutional or transformer-based models, which learn features automatically using raw signals, but which are efficient through edge-sensitive optimization. The system also may be expanded to carry out the disease severity evaluation and evolution through longitudinal patient data. Wearable-based and IoT integration would allow tracking and real-time clinical feedback remotely. Moreover, the use of federated learning methods can be used to increase data privacy as well as enhance model generalization in varied populations. The proposed approach can become a high-tech, all-encompassing approach to the early detection and treatment of neurological disorders with clinical validation and regulatory acceptance.

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