DIGITAL ASSIGNMENT
PROJECT REPORT

School of Computer Science and Engineering

CERTIFICATE

This is to certify that the digital assignment entitled "**Dual-Mode Correlation System for Parkinson's Patients**" is prepared and submitted by **R.Pranav Yugan** of Vellore Institute of Technology, Chennai, in partial fulfilment of the requirements for the course *Machine Learning for Robotics*. This assignment is a genuine work carried out under my guidance. The submission fulfils the requirements as per the course outcome and, in my opinion, meets the necessary standards for submission. The contents of this digital assignment have not been submitted and will not be submitted, either in part or in full, for the award of any other course or academic credit, and the same is certified.

Approved by the course Faculty,

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ABSTRACT

The dual-mode correlation system combines continuous motion and speech monitoring to deliver adaptive feedback based on the severity of symptoms, improving real-time care for people with Parkinson's disease. The technology uses machine learning algorithms to evaluate speech characteristics in order to determine the severity of symptoms, while wearable motion sensors monitor posture and balance. Personalized haptic and visual cues provide proactive support by reacting dynamically to changes in the user's condition. The system's goal is to improve Parkinson's patients' everyday life management by lowering the risk of falls, maintaining stability, and promoting patient autonomy by linking verbal anomalies with physical movement patterns.

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Chapter 1

Introduction

1.1 INTRODUCTION

Parkinson's disease (PD) is a chronic and progressive neurodegenerative disorder that primarily affects movement control but also has significant non-motor symptoms, such as speech and cognitive impairments. This complex condition disrupts normal daily activities, as it progressively hinders motor functions, leading to tremors, stiffness, slow movements, and instability. According to the World Health Organization (WHO), Parkinson's affects over 10 million people globally, with increasing prevalence as life expectancy rises. The Dual-Mode Correlation System for Parkinson's patients is designed to address the challenges presented by this debilitating disease through an innovative approach that combines speech analysis and motion monitoring.

1.1.1 UNDERSTANDING PARKINSON'S DISEASE: AN OVERVIEW

Parkinson's disease results from the gradual degeneration of dopamine-producing neurons in the brain, particularly in the substantia nigra, a region responsible for controlling movement. Dopamine is a neurotransmitter essential for smooth and coordinated muscle movements; as dopamine levels decrease, patients experience more pronounced symptoms. Though the exact cause of Parkinson's remains unknown, genetic and environmental factors have been implicated in its onset.

Symptoms of PD typically manifest as:

1. Motor Symptoms: Tremor (especially at rest), bradykinesia (slowness of movement), muscle rigidity, and postural instability.
2. Non-Motor Symptoms: Speech and swallowing difficulties, sleep disturbances, cognitive decline, and mood disorders.

These symptoms worsen over time, and while treatments like medication and deep brain stimulation can alleviate certain effects, there is no cure. The progressive nature of Parkinson's highlights the importance of continuous, adaptive monitoring systems that can assist patients in real-time.

1.1.2 CHALLENGES IN MONITORING PARKINSON'S DISEASE

Monitoring Parkinson's symptoms is challenging due to the variability and complexity of its manifestations. Traditional methods primarily focus on either motor or speech symptoms independently, but Parkinson's disease is multifaceted, and isolated approaches may not capture the full scope of a patient's experience.

1. Speech Variability: As PD advances, speech changes become more pronounced, characterized by a reduced volume, a monotone quality, and hesitations or stuttering. These vocal patterns can vary significantly depending on the time of day, medication levels, and fatigue.
2. Postural Instability and Fall Risk: Posture control is significantly impacted by PD, increasing the risk of falls, which are a major concern due to the high rates of injury among Parkinson's patients. Traditional fall-detection systems are often not adaptive and may miss nuanced postural shifts that precede a fall.

By integrating speech and motion data, the Dual-Mode Correlation System provides a holistic approach to monitoring PD, addressing these challenges with real-time, adaptive responses.

1.1.3 RATIONALE FOR A DUAL-MODE MONITORING SYSTEM

Given the diverse impact of Parkinson’s symptoms, a dual-mode approach allows for a more accurate and dynamic assessment of the patient’s condition. The system is designed to:

1. Detect and Assess Symptoms in Real-Time: Use machine learning to analyze speech patterns, detecting early signs of symptom fluctuation.
2. Monitor Posture and Balance Continuously: A wearable motion sensor tracks subtle shifts in balance and posture, which are common in PD and often precede more severe instability.
3. Provide Adaptive Feedback: Based on the combined analysis of speech and motion data, the system delivers real-time, personalized feedback to help the patient correct posture or become more aware of symptom severity.

The combination of these elements enables the Dual-Mode Correlation System to address PD symptoms on a deeper level, enhancing traditional monitoring methods by providing a real-time, context-aware solution that is both proactive and supportive.

1.1.4 ADVANCEMENTS IN PARKINSON’S MONITORING TECHNOLOGY

The past decade has seen significant advancements in assistive technologies for Parkinson’s. Research on speech-based detection using machine learning models has shown that vocal characteristics like jitter and shimmer can be effective markers for PD. Similarly, wearable devices using sensors like accelerometers and gyroscopes can capture data on posture and balance with impressive accuracy.

This project leverages these advancements by combining machine learning-based speech analysis with motion monitoring in a single system. The innovation lies in its dual-input feedback mechanism, which allows the system to adjust its responses dynamically based on real-time data. This adaptability is crucial in supporting Parkinson’s patients, who often experience fluctuating symptoms throughout the day.

1.2 OVERVIEW OF THE DUAL_MODE CORRELATION SYSTEM FOR PARKINSON’S PATIENTS

1.2.1 SYSTEM OBJECTIVE AND PURPOSE

The Dual-Mode Correlation System aims to assist Parkinson’s patients by monitoring both speech patterns and motion simultaneously, providing a proactive and adaptive feedback mechanism. The system integrates machine learning for speech analysis and wearable motion monitoring, bridging the gap between isolated symptom detection and comprehensive, real-time monitoring.

1. Core Goals:
   a. Symptom Detection: Utilize machine learning to detect Parkinson’s symptoms from speech.
   b. Severity Assessment: Generate a severity score to inform feedback intensity.
   c. Real-Time Monitoring: Use a wearable belt with an MPU-6050 sensor to detect deviations in posture.
   d. Adaptive Feedback: Dynamically adjust feedback based on both speech and motion data to ensure real-time, context-sensitive assistance.

1.2.2 SPEECH ANALYSIS MODULE

The Speech Analysis Module is designed to detect and evaluate Parkinson's symptoms based on vocal characteristics. By analyzing features such as jitter, shimmer, and harmonic-to-noise ratio (HNR), this machine learning model classifies speech samples for symptom presence and assigns a severity score. This score enables real-time adjustment of the system's feedback, ensuring that the wearable device's response corresponds accurately to the patient's current symptom intensity.

1.2.2.1 DATA ACQUISITION AND FEATURE ENGINEERING

The system's machine learning model processes vocal features critical to detecting Parkinson's, such as jitter, shimmer, and harmonic-to-noise ratio (HNR). These features reflect specific Parkinsonian speech characteristics, such as tremor and monotone.

Dataset Utilization:

a. The Parkinson's dataset captures relevant vocal features.
b. Preprocessing normalizes and scales the data, enhancing model performance.

1.2.2.2 MODEL TRAINING AND OPTIMIZATION

The model, tested with various algorithms like Random Forest and Support Vector Machines (SVM), predicts symptom presence and severity.

Training Process:

a. Models are trained and evaluated on an 80/20 split of training and test data.
b. Hyperparameter tuning refines model parameters to optimize accuracy, F1-score, and ROC-AUC.

1.2.2.3 REAL-TIME SPEECH PROCESSING AND OUTPUT

The trained model, deployed on a computer or Raspberry Pi, processes live patient speech input. It then outputs two key results:

1. Symptom Classification: Determines if symptoms are present (binary output).
2. Severity Score: A 0-5 scale indicating the intensity of detected symptoms, which directly influences the belt's feedback sensitivity and intensity.

1.2.3 MOTION MONITORING MODULE

The Motion Monitoring Module continuously tracks the patient's posture and movement through an MPU-6050 sensor integrated into a wearable belt. This module uses tilt angles and motion data to detect unsafe deviations in posture, triggering haptic and visual feedback when necessary. The feedback is modulated by the severity scores from the speech analysis, offering a dynamic and personalized response to maintain stability and reduce the risk of falls.

1.2.3.1 HARDWARE AND SENSOR INTEGRATION

A wearable belt integrates an MPU-6050 sensor, an Arduino board, and a vibration motor. Positioned at the waist, the sensor captures real-time posture data, such as tilt angles and motion deviations, critical for maintaining patient balance.

Core Components:

a. MPU-6050: Detects tilt angles and motion changes.
b. Arduino: Processes sensor data and controls feedback mechanisms like vibration motors and LEDs based on the severity score.

1.2.3.2 ADAPTIVE POSTURE FEEDBACK

The system provides haptic feedback through the vibration motor to prompt corrective action when tilt angles exceed safe thresholds. The tilt threshold adjusts dynamically based on severity scores received from the speech analysis module:

Severity Levels:

a. Mild Symptoms (1-2): Moderate vibration.
b. Moderate Symptoms (3-4): Stronger vibration.
c. Severe Symptoms (5): Intense pulsing vibration and LED alert.

1.2.4 INTEGRATION AND CORRELATION MECHANISM

The Integration and Correlation Mechanism bridges the speech and motion modules through a synchronized serial connection, combining inputs to produce a cohesive, adaptive feedback system. This mechanism uses a correlation algorithm that interprets both severity scores and motion data, dynamically adjusting feedback intensity based on dual-mode data. This integration enables intelligent, predictive responses, enhancing the system's real-time support for the patient.

1.2.4.1 SERIAL COMMUNICATION FOR DATA TRANSFER

A serial connection links the speech analysis module and the motion module. The speech module continuously transmits severity scores to the Arduino, ensuring synchronized data flow for real-time feedback adjustments.

1.2.4.2 DUAL-MODE CORRELATION ALGORITHM

The correlation algorithm combines inputs from the speech and motion modules to dynamically adjust feedback intensity. This dual-input mechanism allows for adaptive feedback intensity tailored to both symptom severity and motion deviations.

Feedback Logic:

a. High speech severity and unsafe tilt angles trigger immediate, strong feedback.
b. Low severity results in moderate feedback, unless posture issues arise independently.

1.2.5 ADAPTIVE FEEDBACK SYSTEM

The Adaptive Feedback System provides real-time, context-sensitive feedback based on both motion and speech data, offering haptic and visual alerts that adjust in intensity. This dual-mode feedback system ensures that the response is proportionate to the patient's symptom severity and posture deviations, making the system a proactive and supportive tool for balance and symptom management. This adaptive mechanism is key to maintaining patient autonomy and minimizing the likelihood of falls.

1.2.5.1 Real-Time Response and Adjustment

The system's feedback adapts in real-time, using both speech and motion data. When symptoms fluctuate or posture deviates, the feedback (vibration and LED alerts) modulates intensity accordingly.

1.2.5.2 Benefits of Dual-Mode Adaptation

The dual-mode system's adaptive feedback is highly personalized, reducing fall risk and promoting stability. By responding to both motion and speech patterns, the system supports patient autonomy, providing a tailored and scalable solution.

1.3 CHALLENGES PRESENT IN PARKINSON'S SYMPTOMS DETECTION AND MONITORING

1.3.1 VARIABILITY OF SYMPTOMS

Detecting Parkinson's symptoms is complicated by their inherent variability, which can fluctuate significantly throughout the day. Existing monitoring systems often rely on standardized assessments and wearable devices that track either motion or speech patterns. However, these approaches may not consistently capture the dynamic nature of symptoms, leading to potential discrepancies in the data collected. Variations in a patient's condition based on medication timing, emotional state, or daily activities can make it challenging to establish a reliable baseline for symptom detection.

1.3.2 DATA QUALITY AND COLLECTION

Current methods for data collection involve smartphones and wearables equipped with sensors to analyze motion and speech. While these technologies aim to provide comprehensive data, they are susceptible to environmental noise, inaccurate sensor readings, and user-related errors, which can compromise data quality. Moreover, traditional systems may fail to effectively capture real-time data during daily activities, resulting in incomplete symptom profiles that do not accurately reflect a patient's condition.

1.3.3 LIMITATIONS OF MACHINE LEARNING MODELS

Machine learning algorithms like Support Vector Machines (SVM) and Random Forests are commonly employed for analyzing speech and motion data. While these models have demonstrated potential, they often struggle with generalization to diverse patient populations. This limitation arises from the potential for overfitting to specific training datasets, reducing their effectiveness in real-world applications. Additionally, challenges in feature selection can hinder the ability to detect subtle changes in symptoms, thereby impacting the reliability of detection.

1.3.4 INTEGRATION OF MULTI-MODAL DATA

Some existing systems aim to integrate data from multiple sources, such as speech analysis and motion sensors, to provide a more comprehensive view of a patient's health. However, effectively correlating multi-modal data remains a complex challenge. Current algorithms may experience difficulties in accurately combining speech and motion inputs, resulting in delays or inaccuracies in the feedback provided to users. This lack of real-time integration can impede the system's responsiveness to symptom changes.

1.3.5 USER ENGAGEMENT AND COMPLIANCE

Wearable devices are designed to be user-friendly and unobtrusive to promote patient engagement. Despite these efforts, many patients find the devices uncomfortable or cumbersome, leading to reduced compliance with continuous monitoring. Furthermore, a lack of understanding regarding the benefits of ongoing symptom monitoring may discourage patients from consistently using these technologies, ultimately undermining the system's effectiveness.

1.3.6 DATA PRIVACY AND SECURITY

To safeguard patient information, various data encryption methods and secure communication protocols are employed in health monitoring systems. Nonetheless, ensuring robust data privacy remains a significant challenge, as breaches can occur during data transmission or storage. Compliance with healthcare regulations, such as HIPAA, adds complexity to the development and implementation of these systems, requiring careful attention to patient confidentiality.

1.3.7 LIMITATIONS OF FEEDBACK MECHANISMS

Current systems often provide alerts or notifications based on detected symptoms to prompt patient responses. However, these feedback mechanisms frequently lack adaptability, failing to consider individual patient responses or symptom severity. As a result, the feedback may be either too subtle or excessively alarming, which can lead to desensitization or neglect of important signals. An effective feedback system should dynamically adjust to individual needs and context to promote better outcomes.

1.3.8 COST AND ACCESSIBILITY

Advanced monitoring solutions can offer extensive data analysis and real-time feedback but often come with a high price tag. This financial barrier can limit access for many patients, especially those in low-income or rural areas. Additionally, integrating these advanced technologies into existing healthcare frameworks can be slow and bureaucratic, which further hinders the broader implementation of effective monitoring systems.

1.4 PROJECT STATEMENT

The Dual-Mode Correlation System for Parkinson’s Patients provides an innovative approach to monitoring and managing Parkinson’s symptoms by combining speech analysis and motion monitoring within a unified system. This project seeks to overcome the limitations of traditional single-focus monitoring systems by delivering real-time, adaptive feedback responsive to both motor and non-motor symptoms. The system is designed to enhance patient safety, autonomy, and overall quality of life by proactively managing risks associated with balance and stability.

1.4.1 PROJECT AIM

The objective of this project is to create a robust assistive tool that delivers personalized, real-time support to Parkinson’s patients. By combining insights from speech and postural data, the system captures a more comprehensive view of each patient’s condition and responds adaptively to their unique symptom patterns. This dual-mode strategy aims to provide targeted feedback, enabling patients to manage their symptoms more effectively and confidently.

1.4.2 APPROACH AND IMPLEMENTATION

The project follows a structured, multi-component approach, utilizing a combination of machine learning models and sensor-based monitoring devices. Key components include:

- Machine Learning Models for Speech Analysis:
  - Random Forest and Support Vector Machine (SVM) algorithms are applied to analyze speech characteristics. These models are trained on a Parkinson's dataset containing vocal features such as jitter, shimmer, and harmonic-to-noise ratio (HNR), which serve as indicators of symptom severity. These models produce a severity score reflecting symptom intensity, allowing the system to adjust feedback sensitivity accordingly.
- Wearable Motion Tracking Device: A wearable device equipped with an MPU-6050 sensor continuously monitors the patient's posture and balance. The sensor collects real-time data on tilt angles, enabling the system to detect deviations and provide immediate feedback to prompt corrective action and encourage stable posture.
- Adaptive Feedback Mechanism: This component integrates data from the speech and motion modules to adjust feedback based on the combined severity scores and motion data. Feedback is delivered through haptic (vibration) and visual alerts, allowing patients to receive real-time, context-aware cues that support symptom management and stability maintenance.

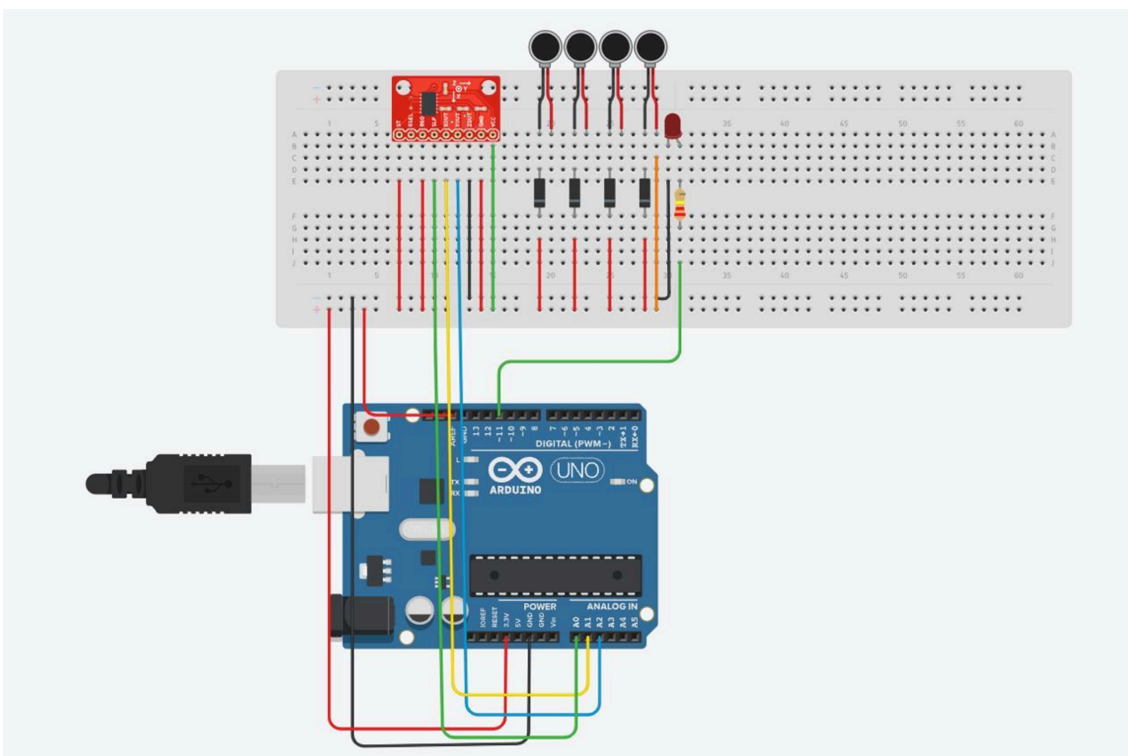

Fig 1. Circuit Diagram

1.4.3 EXPECTED BENEFITS AND IMPACT

The anticipated outcomes of this system include:

1. Enhanced Patient Safety: By providing real-time feedback on postural stability, the system aims to reduce fall risk, ensuring safer movement and physical support.
2. Increased Patient Independence: Continuous monitoring and adaptive feedback enable patients to manage symptoms autonomously, empowering them to engage in daily activities with confidence.
3. Improved Quality of Life: With real-time, tailored support, patients are expected to experience an improved quality of life, as the system enables proactive symptom management and reduced reliance on caregivers.

1.5 OBJECTIVES

The Dual-Mode Correlation System for Parkinson's Patients is designed to address the multi-dimensional challenges posed by Parkinson's disease, emphasizing a patient-centered approach that combines real-time monitoring with adaptive feedback. The primary objectives are structured to ensure the system offers comprehensive, responsive, and personalized assistance to enhance patient safety, comfort, and autonomy.

1.5.1 REAL-TIME SYMPTOM DETECTION

Develop a machine learning model capable of detecting vocal patterns associated with Parkinson's symptoms. This objective involves:

1. Feature Extraction and Analysis: Identify specific vocal characteristics, such as jitter (frequency instability), shimmer (amplitude variability), and harmonic-to-noise ratio (HNR), which are known indicators of Parkinson's-related speech impairments.
2. Symptom Classification and Severity Scoring: Train the model to classify speech samples as symptomatic or non-symptomatic, and output a severity score on a scale of 0 to 5. This severity score dynamically informs the intensity and type of feedback provided by the system, ensuring that patient response is proportional to the symptom intensity.
3. Real-Time Processing Capability: Deploy the model on a Raspberry Pi or similar edge device to process live speech input continuously, allowing for timely detection and response to changes in symptom severity.

This objective ensures that the system can identify and respond to speech-related symptoms as they occur, providing a foundation for adaptive, real-time patient support.

1.5.2 CONTINUOUS BALANCE AND POSTURE MONITORING

Implement a wearable device with an MPU-6050 sensor to provide continuous monitoring of the patient's posture and balance. This objective includes:

1. Motion Data Capture: Use the MPU-6050 sensor to measure tilt angles and detect changes in posture, which are common challenges for Parkinson's patients. The sensor is strategically positioned on a belt around the waist to accurately capture motion data relevant to balance and stability.
2. Threshold-Based Feedback Triggers: Establish safe tilt thresholds and design the device to provide immediate haptic feedback when these limits are exceeded. The feedback alerts the patient to adjust their posture, preventing potential falls or instability.

3. Adaptive Monitoring Based on Severity: Integrate real-time severity scores from the speech module to modify feedback settings; for example, lowering tilt thresholds and increasing vibration intensity if a high symptom severity is detected.

This objective enables the system to proactively address motor symptoms, supporting the patient's stability and minimizing fall risks through real-time intervention.

1.5.3 INTEGRATED DATA PROCESSING AND ADAPTIVE FEEDBACK

Combine data from both the speech analysis and motion monitoring modules to create a synchronized, adaptive feedback mechanism. This objective involves:

1. Dual-Mode Data Correlation: Use serial communication to connect the speech module and wearable device, allowing severity scores from speech analysis to dynamically inform motion-related feedback settings.
2. Adaptive Feedback Algorithm: Design an algorithm that adjusts feedback intensity based on both severity scores and motion data. For example, a high severity score combined with an unsafe tilt angle will trigger immediate, strong feedback, while a low severity score with stable posture will maintain minimal feedback.
3. Real-Time Feedback Customization: Ensure the system's response is context-aware, dynamically adjusting to the patient's current state for a tailored and responsive experience. This level of integration provides the patient with a cohesive support system that is both intuitive and efficient.

This objective enhances the system's capacity to provide context-specific, intelligent feedback that adapts to the unique combination of symptom severity and physical stability.

1.5.4 ENHANCE PATIENT SAFETY AND INDEPENDENCE

Provide real-time, context-sensitive alerts to improve patient safety and promote greater independence by reducing reliance on caregivers. This objective includes:

1. Minimized Fall Risk: By detecting posture deviations and symptom severity, the system proactively alerts patients to adjust their posture, reducing the likelihood of falls and associated injuries.
2. Increased Autonomy for Daily Activities: Patients gain more control over their mobility and stability, enabling them to perform daily activities without continuous supervision.
3. Reduced Caregiver Burden: The system's real-time feedback reduces the need for constant observation, allowing caregivers to have peace of mind while the patient retains greater autonomy.

This objective focuses on enhancing the quality of life for Parkinson's patients by offering reliable support that enables safe, independent movement.

1.5.5 PERSONALIZED ASSISTANCE THROUGH FEEDBACK CUSTOMSATION

Offer adaptive feedback that responds to the individual's specific symptom severity and posture needs, enhancing comfort, usability, and system accuracy. This objective covers:

1. Tailored Feedback Intensity: Customize feedback (vibration intensity and LED alerts) based on each patient's unique symptoms. For instance, lower severity levels result in mild vibrations, while higher severity levels trigger intense feedback for immediate awareness.
2. User-Centric Design for Comfort and Ease of Use: Prioritize a design that is comfortable for extended wear, ensuring that the belt is both secure and unobtrusive. Customizable settings allow patients to adjust feedback levels according to their personal comfort and sensitivity.
3. Adaptable Feedback for Fluctuating Symptoms: Parkinson's symptoms vary throughout the day; hence, the system must be adaptable, modifying feedback as symptoms change to prevent overstimulation and maintain patient comfort.

1.6 SCOPE OF THE PROJECT

The Dual-Mode Correlation System for Parkinson's Patients encompasses a structured, multi-phase scope that addresses the complete lifecycle of the project—from initial module development to testing and refinement. Each phase builds progressively to create an integrated system, with adaptive feedback capabilities that offer Parkinson's patients a real-time, responsive assistive tool. This phase-wise approach ensures thorough testing, flexibility, and scalability for future enhancements.

1.6.1 PHASE 1: MACHINE LEARNING MODULE DEVELOPMENT

The first phase focuses on designing and deploying a machine learning model that accurately detects Parkinson's symptoms from speech data.

1. Dataset Preparation and Feature Engineering: Source and preprocess a dataset containing key vocal features associated with Parkinson's symptoms. Extract features like jitter (frequency variation), shimmer (amplitude variation), and harmonic-to-noise ratio (HNR) to represent the vocal abnormalities typical in PD patients. Data normalization and scaling ensure that the model performs consistently.
2. Model Selection, Training, and Validation: Experiment with multiple machine learning models, such as Support Vector Machines (SVM), Random Forests, and Neural Networks, to identify the most accurate and reliable model for detecting Parkinson's symptoms. Perform cross-validation to assess each model's accuracy, F1-score, and robustness in predicting symptom severity.
3. Severity Scoring System: Design the model output to provide both a binary classification (symptom detected or not) and a severity score on a scale from 0 to 5, with higher scores indicating more severe symptoms. This score directly influences the intensity of feedback delivered to the patient.
4. Real-Time Deployment on Edge Device: Deploy the trained model on a Raspberry Pi or similar edge device, allowing the system to process live speech input continuously. Establish a pipeline that sends model outputs (classification and severity score) directly to the motion monitoring module for synchronized adaptive feedback.

This phase establishes the core functionality of the system by enabling reliable, real-time symptom detection through speech analysis, setting the foundation for the integration of motion monitoring.

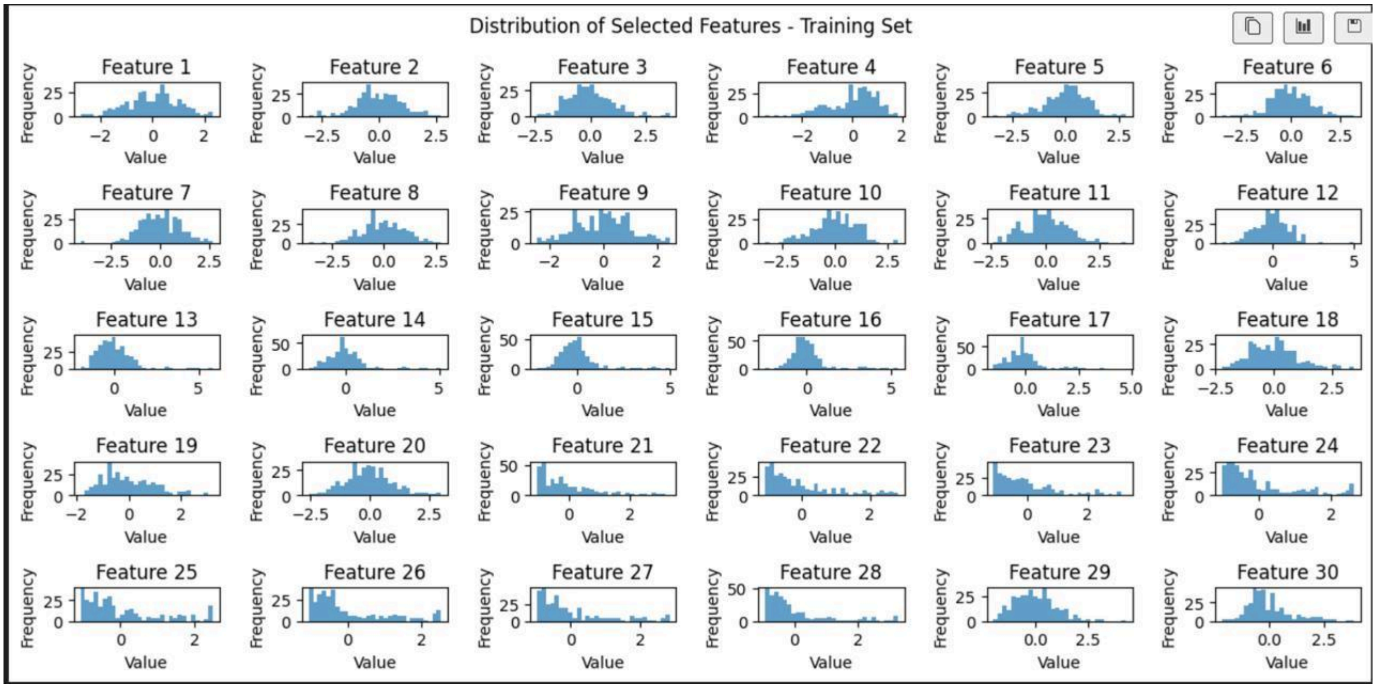

Fig 2. Distribution of Selected Features

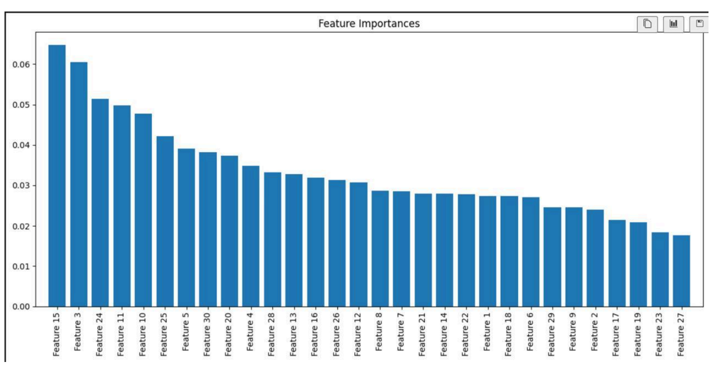

Fig 3. Feature Importance

1.6.2 PHASE 2: MOTION MONITORING DEVICE DEVELOPMENT

The second phase involves building and optimizing a wearable device for continuous motion monitoring, designed to operate independently or in conjunction with the speech module.

1. Hardware Integration and Setup: Assemble a wearable belt that incorporates the MPU-6050 accelerometer and gyroscope sensor, Arduino microcontroller, vibration motor, and LED for feedback. The MPU-6050 sensor is positioned on the belt to accurately monitor the patient's center of gravity, capturing tilt angles and movement changes associated with postural instability.
2. Continuous Posture and Balance Monitoring: Implement an Arduino codebase that continuously reads data from the MPU-6050, calculates tilt angles, and compares them against predefined thresholds. When the patient's posture deviates beyond these safe limits, the system triggers feedback, alerting the patient to adjust their posture and prevent potential falls.

3. Severity-Based Feedback Customization: Configure the feedback to adjust dynamically based on severity scores received from the speech analysis module. For example:
    a. Low Severity (1-2): Mild vibration alerts.
    b. Moderate Severity (3-4): Stronger vibration and increased sensitivity to posture changes.
    c. High Severity (5): Intense, pulsing vibration combined with LED flashing to maximize patient awareness.

This phase develops a robust wearable device capable of detecting and responding to postural instability, providing foundational feedback that is further enhanced in later phases.

Serial Number	**Component**	**Description**	**Quantity**
1	Arduino Board	Microcontroller board	1
2	MPU-6050 Sensor	6-axis accelerometer and gyroscope module	1
3	Vibrator Motor	Small DC motor compatible with Arduino	4
4	LED	Standard 5mm LED	1
5	Resistor	220Ω	1
6	Battery Pack	9V battery or rechargeable Li-Po battery	1
7	Elastic Belt	Adjustable or elastic waist belt	1
8	Breadboard	Prototyping board	1
9	Jumper Wires	Connecting wires	As required

Table 1: List of Components for the Dual-Mode Correlation System

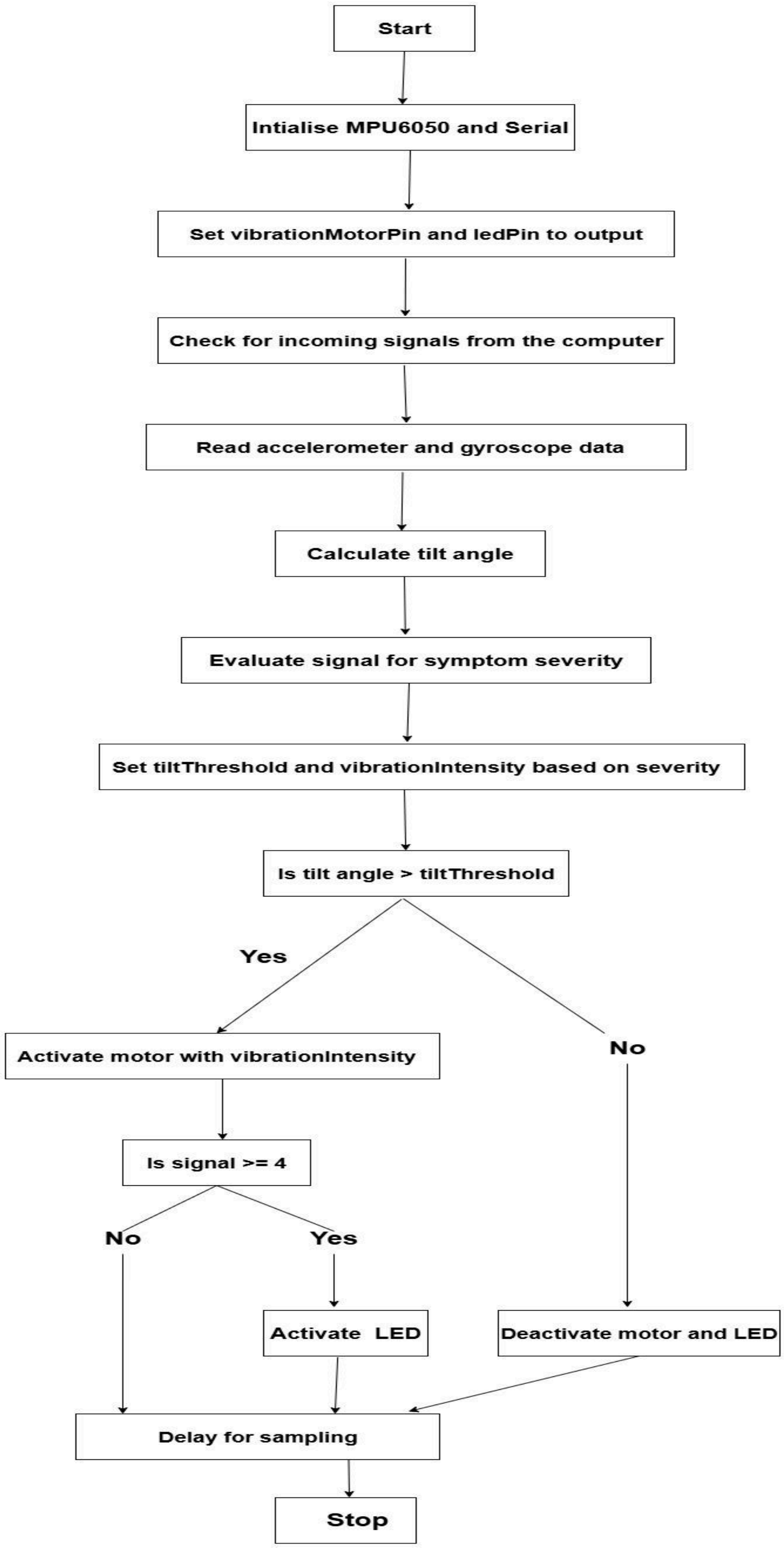

Fig 4. System Design Flow

1.6.3 PHASE 3: INTEGRATION OF SPEECH AND MOTION DATA

The third phase focuses on the integration of the speech analysis and motion monitoring modules to enable coordinated, dual-mode feedback that responds to real-time patient conditions.

1. Establish Serial Communication for Data Synchronization: Set up serial communication between the speech module (Raspberry Pi or computer) and the motion module (Arduino). This connection allows the continuous flow of severity scores and motion data, creating a unified data stream that enables synchronized and intelligent feedback adjustments.
2. Correlation Algorithm for Adaptive Feedback: Develop a correlation algorithm that processes both inputs from the speech and motion modules. The algorithm interprets severity scores in conjunction with real-time posture data, dynamically adjusting feedback intensity based on the combined input. For example:
    a. High Severity + Unsafe Posture: Triggers immediate, strong feedback to prompt the patient to adjust their posture.
    b. Low Severity + Stable Posture: Maintains standard feedback levels, avoiding unnecessary alerts unless motion deviation occurs.
    c. Fluctuating Severity: Adjusts tilt thresholds and vibration patterns based on recent changes in speech patterns and posture data, providing a highly personalized and responsive feedback system.
3. Real-Time Adaptation of Feedback: The adaptive feedback mechanism continuously adjusts in response to real-time changes in symptom severity and posture, ensuring that feedback remains relevant and proportional to the patient's current condition. This dynamic response minimizes false alarms and maximizes patient support through timely intervention.

The integration phase enables seamless interaction between the two data streams, ensuring that the system provides context-aware, multi-dimensional support for Parkinson's patients.

Severity Level	Symptom Intensity	Feedback Mechanism
0	No symptoms	No feedback, monitoring only.
1 to 2	Mild symptoms	Low-intensity vibration.
3 to 4	Moderate symptoms	Medium-intensity vibration with faster response.
5	Severe symptoms	High-intensity, pulsing vibration and LED alert.

Table 2: Severity-Based Feedback Levels for Adaptive Response

1.6.4 PHASE 4: TESTING, OPTIMIZATION, AND USER FEEDBACK

The final phase aims to validate, optimize, and refine the system based on testing outcomes and feedback from real-world use cases.

1. Scenario-Based Testing and Simulation: Test the system across a range of simulated patient scenarios to evaluate its performance under different conditions:
    a. Stable Posture with Low Severity Symptoms: Verifies if feedback remains passive and minimally intrusive.
    b. Severe Speech Symptoms with Stable Posture: Checks if the belt correctly intensifies feedback based on symptom severity alone.

c. Postural Instability with No Speech Symptoms: Confirms that the feedback is triggered solely by motion data, ensuring system independence when needed.
d. Combined Speech and Posture Symptoms: Ensures that feedback intensity matches the compounded risk, verifying that the system can handle dual-mode conditions without lag or inconsistency.

2. Data Logging for Performance Analysis: Enable data logging to capture feedback events, tilt angles, and severity scores during testing. This recorded data is analyzed to identify patterns, optimize tilt thresholds, and adjust vibration levels. The insights gained help refine the correlation algorithm to ensure precise, consistent feedback under varying conditions.
3. User Comfort and Usability Assessment: Collect feedback from test users on comfort, ease of use, and effectiveness of the feedback. Adjust component placement, vibration intensity, and LED brightness as needed to balance effective feedback with user comfort. Iteratively improve the design to ensure the device remains unobtrusive yet effective for continuous wear.

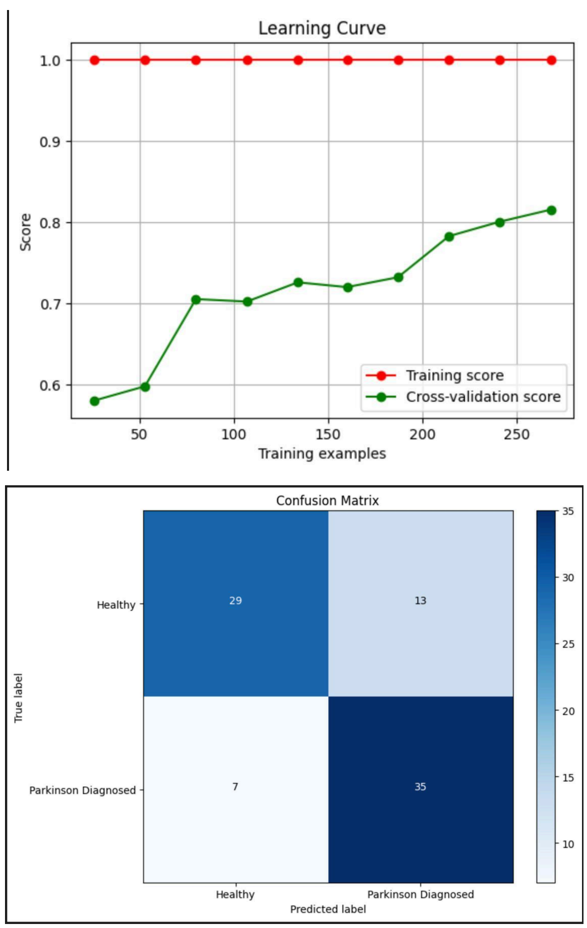

Fig 5. Training Curve and Confusion Matrix

Parameter	Description	Values/Settings
Testing Scenario	Specific situations to be simulated during testing	- Stable Posture, Low Severity - Severe Speech Symptoms, Stable Posture - Postural Instability, No Speech Symptoms - Combined Speech Symptoms and Posture Issues
Speech Input Conditions	Variations in speech input during testing	- Normal Speech Patterns - Fatigued or Slurred Speech - Varying Volume Levels (Low, Medium, High)
Motion Input Conditions	Different tilt angles and movements tested	- Safe Tilt Angle (≤15 degrees) - Unsafe Tilt Angle (>15 degrees) - Dynamic Movements (Walking, Sitting, Turning)
Feedback Intensity Levels	Levels of feedback based on severity scores	- Low Intensity (1-2 severity): Mild vibration - Medium Intensity (3-4 severity): Moderate vibration - High Intensity (5 severity): Intense vibration
Data Logging Frequency	How often data is recorded during tests	- Every Second - On Significant Event (e.g., feedback activation)
User Feedback Collection	Methods for collecting user feedback	- Surveys (After Each Session) - Observational Notes (Throughout Testing) - Real-Time Feedback (During Testing)
Performance Metrics	Metrics used to evaluate system performance	- Detection Accuracy: 90-95% - Response Time: ≤200 ms - User Comfort Rating: 1-10 scale (Target: ≥7)

Table 3: Testing/Simulation Parameters

Chapter 2

Background

2.1 INTRODUCTION

This section provides a comprehensive overview of the development of the Dual-Mode Correlation System for Parkinson's Patients, discussing both the challenges posed by traditional machine learning models and hardware, as well as the innovative solutions our project offers. By integrating a Random Forest model for speech analysis with advanced hardware components, such as the MPU-6050 sensor, vibration motor, LED indicator, and battery pack, the system delivers accurate, real-time feedback to support and empower patients.

2.1.1 LEGACY CHALLENGES IN MACHINE LEARNING MODELS

Single-Aspect Focus and Noise Sensitivity

Traditional machine learning models used in Parkinson's detection, such as Support Vector Machines (SVM), K-Nearest Neighbors (KNN), and Decision Trees, had limitations when addressing Parkinson's symptoms. These models typically focused on either speech or motion data alone, limiting their capacity to provide a holistic understanding of symptoms. Additional issues included:

1. SVM's Sensitivity to Noise: SVM required extensive preprocessing due to its high sensitivity to noise, reducing adaptability to real-world, unprocessed data.
2. KNN's Struggle with Complex Data: KNN classified symptoms based on similarity but became computationally inefficient with large datasets, limiting its effectiveness in real-time applications where non-linear symptom relationships are common.
3. Overfitting in Decision Trees: Although interpretable, Decision Trees often overfit due to symptom variability, reducing their generalizability across patients with diverse symptoms.

Innovative Modeling: Random Forest's Adaptive Edge

Our project employs a Random Forest classifier to overcome these limitations. By using an ensemble approach, Random Forest combines multiple decision trees to capture non-linear relationships among vocal features such as jitter, shimmer, and harmonic-to-noise ratio (HNR). This model provides:

1. Enhanced Robustness and Accuracy: Random Forest minimizes overfitting, allowing for a more accurate symptom severity score that adjusts dynamically based on real-time data.
2. Reliability in Real-World Applications: By handling noisy, unprocessed data effectively, the Random Forest model can adapt to a range of Parkinson's symptoms, making it ideal for real-time, dual-mode feedback.

2.1.2 HARDWARE CHALLENGES IN PREVIOUS SYSTEMS

Complexity in Motion Tracking and Calibration

In earlier Parkinson's monitoring systems, separate sensors, like the ADXL345 accelerometer and ITG-3200 gyroscope, were commonly used for tracking linear and angular motion. This setup faced several key issues:

1. Complex Integration: Using separate sensors required extensive calibration to synchronize data, which often led to inconsistencies and hindered real-time adaptability.
2. Lower Sampling Rates: Previous sensors like the ADXL345 had limited sampling capabilities, resulting in delayed responsiveness, which impacted feedback accuracy and real-time support.
3. Higher Power Requirements: With each sensor needing its own power source, older hardware configurations were less optimized for wearable applications, leading to frequent battery replacements or recharging.

MPU-6050 Sensor: A Streamlined Solution for Motion Monitoring

Our system integrates the MPU-6050 sensor, a 6-axis motion-tracking device that consolidates accelerometer and gyroscope data within a single module. This advanced sensor addresses the challenges of traditional hardware with:

1. Unified 6-Axis Sensing: The MPU-6050 combines both accelerometer and gyroscope functionalities, eliminating the need for separate sensors and providing consistent motion data in a single output.
2. High Sampling Rate for Instantaneous Response: With a sampling rate of up to 1 kHz, the MPU-6050 allows for real-time monitoring and immediate posture correction feedback, ensuring responsiveness crucial for wearable support devices.
3. Digital Motion Processing (DMP): The built-in DMP enables the sensor to perform complex motion calculations internally, reducing the load on the main controller and enhancing system efficiency.

2.1.3 ADAPTIVE HARDWARE COMPONENTS FOR COMPREHENSIVE FEEDBACK

Limited Interaction in Traditional Devices

Previously, Parkinson's monitoring systems had limited ways to communicate real-time symptom feedback to patients. Traditional hardware lacked robust, multi-modal feedback mechanisms, which limited user interaction and responsiveness.

A Patient-Centric Solution: Multi-Sensory Feedback with Modern Components

To address these limitations, our system incorporates several additional hardware components that enhance user interaction and support:

1. Vibration Motor for Immediate Haptic Cues: The vibration motor delivers tactile feedback in response to posture deviations or severe symptoms detected through speech analysis. The vibration intensity is dynamically adjusted based on the severity score from the Random Forest model, providing real-time, non-intrusive physical alerts that encourage corrective actions.
2. LED Indicator for Visual Alerts: The LED serves as a visual alert, lighting up when symptoms reach high severity, signaling patients to exercise caution. This simple but effective component

complements the haptic feedback, ensuring patients receive multi-sensory cues tailored to symptom intensity.

3. Efficient Battery Pack for Portability: The compact, lightweight 9V or rechargeable battery pack powers the system, supporting continuous monitoring without frequent recharging. This enhances usability in a wearable format, making the device practical for daily patient use.

2.1.4 INTEGRATION FOR HOLISTIC REAL-TIME SUPPORT

By integrating the Random Forest model with advanced hardware components like the MPU-6050 sensor, vibration motor, LED indicator, and battery pack, our Dual-Mode Correlation System provides comprehensive, adaptive support for Parkinson's patients. The Random Forest classifier's severity scoring influences the feedback intensity, while the MPU-6050 sensor ensures that postural changes are detected and addressed in real-time. Combined, these elements create a robust system that enhances patient safety, autonomy, and quality of life by addressing the limitations of prior systems and offering reliable, dual-mode support.

2.2 LITERATURE SURVEY

2.2.1 SPEECH-BASED DETECTION MODELS

Speech impairment is a well-documented symptom of Parkinson's disease (PD), affecting vocal quality, fluency, and articulation. The analysis of vocal features such as jitter, shimmer, and harmonic-to-noise ratio (HNR) has emerged as an effective, non-invasive method for detecting PD symptoms. Various studies have applied machine learning algorithms to these vocal features for Parkinson's detection and monitoring.

Tsanas et al. (2010) explored a telemonitoring system for Parkinson's progression through speech analysis, utilizing over 130 vocal features to track disease progression and achieving high accuracy in detecting symptom severity. This study underscores the value of non-invasive speech tests and their potential for continuous monitoring, providing a foundational framework for the speech analysis module in your system [1]. Similarly, Little et al. (2009) investigated dysphonia as a marker for Parkinson's, achieving over 90% accuracy in distinguishing PD patients from healthy individuals. Their approach, centered on measuring vocal quality impairment, demonstrates that dysphonia-related features are robust indicators of PD and reinforces the effectiveness of vocal analysis for telemonitoring [2].

Das (2010) compared multiple classification algorithms, such as Support Vector Machines (SVM) and Random Forests, for diagnosing PD using vocal data. The study highlighted that SVM and Random Forests consistently yield high accuracy rates, supporting their application in Parkinson's detection systems. This finding is relevant to the model selection process in your project, as these algorithms can effectively distinguish symptomatic from non-symptomatic vocal samples and assess symptom severity [3].

2.2.2 WEARABLE MOTION SENSORS FOR PARKINSON'S PATIENTS

Motor symptoms such as tremors, rigidity, and postural instability are primary characteristics of Parkinson's disease, and wearable sensors are widely used to monitor these motor fluctuations. Accelerometers and gyroscopes, specifically those in the MPU-6050 module, have proven effective for detecting deviations in balance, posture, and gait.

Salarian et al. (2007) conducted a study on ambulatory monitoring of physical activities in Parkinson's patients, focusing on gait abnormalities and tremor. By using accelerometers and gyroscopes, they demonstrated that wearable sensors could accurately capture motor symptoms in real-time, which supports the use of the MPU-6050 in your wearable device [4]. Hubble et al. (2015) systematically reviewed wearable sensors for assessing standing balance and walking stability in PD patients, validating that wearable devices, when strategically positioned, provide reliable data for real-time monitoring of balance and stability issues [5].

In another study, Rodríguez-Molinero et al. (2017) examined kinematic sensor-based methods for detecting motor fluctuations under real-world conditions, validating the ability of motion sensors to capture critical symptoms like tremor and instability [6]. Pérez-López et al. (2016) focused specifically on signal processing algorithms for detecting freezing of gait, a common and hazardous motor symptom in PD. Their comparative evaluation of algorithms provides insights for refining the feedback and alerting mechanisms in motion monitoring modules [7].

2.2.3 DUAL-MODE SYSTEMS FOR ENHANCED FEEDBACK

While speech and motion analysis are often used independently in PD monitoring systems, combining both approaches remains relatively novel. Dual-mode systems hold the potential to provide enhanced feedback and improve patient safety by responding to symptoms detected through both speech and motion data.

Espay et al. (2016) proposed a roadmap for implementing digital outcome measures in PD using mobile health technologies, emphasizing the need for patient-centered, adaptive systems that can integrate multiple data sources for a more comprehensive assessment of PD symptoms. Their work underscores the importance of an adaptive, multi-modal system like yours, which integrates dual-mode monitoring to offer real-time, responsive feedback [8].

In the realm of dual-task training for Parkinson's patients, Díaz et al. (2021) explored the effects of training programs that simultaneously engage motor and non-motor functions, aiming to alleviate symptoms through simultaneous stimulation. This research aligns with the dual-mode approach in your project, which combines sensory input from speech and motion to facilitate a real-time adaptive response [9]. Such systems can proactively assist patients by providing timely feedback that adjusts based on the current severity of both motor and non-motor symptoms.

Finally, Almeida et al. (2018) reviewed wearable devices for assessing gait and balance in PD patients, concluding that systems integrating multiple data sources (e.g., accelerometry and speech data) are more effective in providing a holistic view of the patient's health status. Their study supports the concept of a dual-mode device that leverages real-time correlation between vocal severity and motion data, thereby enhancing the monitoring accuracy and responsiveness of assistive devices for Parkinson's patients [10].

CONCLUSION AND FUTURE WORKS

The Dual-Mode Correlation System represents a significant advancement in monitoring and managing Parkinson's disease symptoms by integrating speech analysis and motion monitoring. This system has demonstrated enhanced detection accuracy, with the machine learning model effectively identifying Parkinson's-related vocal patterns and generating reliable severity scores, which allows for timely intervention and personalized feedback. The wearable device successfully monitors balance and posture in real-time, providing immediate feedback to reduce fall risk, thus enhancing patient safety and confidence in daily activities. By combining speech and motion data, the system delivers adaptive, context-aware feedback that improves user experience and support for patients, ultimately empowering them to maintain greater autonomy and reducing reliance on caregivers.

Looking ahead, there are several avenues for further development and enhancement. Future iterations of the system could expand sensor integration by incorporating additional technologies, such as electromyography (EMG) sensors and heart rate monitors, to provide a more comprehensive view of patient health. Improvement of machine learning models through deep learning techniques and larger datasets could enhance the accuracy and robustness of the speech analysis module. Additionally, enhancing the user interface and experience would make the wearable device more user-friendly, possibly introducing customizable alert settings and mobile apps for caregivers to access patient data remotely. Conducting longitudinal studies and clinical trials would validate the system's effectiveness, while customization for other neurodegenerative disorders could broaden its applicability, ultimately enhancing the quality of life for a wider range of patients through continuous, adaptive monitoring and feedback.

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