NEUROSTIMULATIVE ASSISTIVE DEVICE FOR PARKINSON DISEASE

Aman Maharaj

Submitted to: JMIR Biomedical Engineering
on: March 05, 2025

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Aman Maharaj[1] BPharm

[1] Wockhardt (India) Daman and diu IN

Corresponding Author:
Aman Maharaj BPharm

Wockhardt (India)
Bhimpore, Nani Daman
Daman and diu
IN

Abstract

Background: Parkinson’s disease (PD) is a progressive neurodegenerative disorder characterized by motor impairments, including tremors, rigidity, and bradykinesia. These symptoms significantly affect patients' daily activities and quality of life. Current treatment options, such as medication and deep brain stimulation (DBS), have limitations, including side effects and high costs. Therefore, there is a need for an alternative, non-invasive assistive solution to improve motor function in Parkinson’s patients.

Objective: The objective of this study is to develop a brain-body interface that utilizes EEG, EMG, and FES to assist Parkinson’s patients in controlling their motor movements. By synchronizing neural and muscular signals, the system aims to facilitate voluntary movement and reduce tremors without invasive procedures. This research seeks to establish a theoretical model for signal processing and movement generation, forming the foundation for future prototype development and clinical validation.

Methods: This section provides a detailed explanation of the methodology used in developing the Parkinson’s assistive device. The approach involves multiple components, each playing a crucial role in capturing, processing, and responding to neurological and muscular signals to facilitate controlled movement.
i. EEG Sensor
Electroencephalography (EEG) sensors are used to capture brain signals, specifically detecting neural activity associated with movement intention. The EEG data is processed using signal processing algorithms to extract relevant patterns that indicate the user's intent to move a specific muscle group.
ii. EMG Sensor
Electromyography (EMG) sensors detect electrical activity in muscles. These sensors help in monitoring voluntary and involuntary muscle contractions. By integrating EEG and EMG data, the system enhances the accuracy of movement prediction and stimulation.
iii. Functional Electrical Stimulation (FES)
FES is used to generate electrical impulses that stimulate specific muscles, facilitating movement in patients experiencing tremors or rigidity. The FES unit receives processed signals from the STM32 microcontroller, ensuring precise and controlled stimulation.
iv. STM32 Microcontroller
The STM32 microcontroller serves as the central processing unit, responsible for handling signals from EEG and EMG sensors, processing them using machine learning algorithms, and sending appropriate stimulation signals to the FES system. It ensures real-time synchronization between brain activity, muscle response, and electrical stimulation.
v. Battery System
The device is powered by a rechargeable battery system, providing a stable and efficient energy supply. Power management circuits are implemented to optimize energy consumption, ensuring long-term usability without frequent recharging.
vi. Signal Processing and Data Flow
? EEG signals are collected and filtered to remove noise.

? EMG signals are simultaneously captured to correlate neural activity with muscle activity.
? The STM32 microcontroller processes these signals and applies machine learning models to predict intended movement.
? The microcontroller sends precise electrical stimulation commands to the FES unit.
? The FES unit stimulates the target muscles, enabling controlled movement.
vii. Synchronization and Feedback Mechanism
To improve accuracy, a feedback loop is implemented where real-time responses from the muscles (EMG) are re-evaluated, and adjustments are made dynamically to the stimulation parameters. This ensures adaptive and efficient motor control.

Results: In this study, a theoretical model was developed to integrate EEG, EBG, and EMG signals for effective control of Functional Electrical Stimulation (FES) in Parkinson’s patients. The preliminary analysis of signal synchronization and processing suggests that this approach has the potential to facilitate controlled motor movements.
1. Theoretical Validation: The signal processing framework was designed based on existing neurophysiological principles. The expected interactions between EEG and EMG signals indicate that FES can be triggered appropriately to induce movement.
2. Expected Outcomes: The anticipated result of this system is an improvement in motor function for Parkinson’s patients by translating neural intent into physical action. The model predicts that synchronized stimulation can assist in reducing tremors and enhancing voluntary movements.
3. Future Work: The next phase involves developing a prototype for real-world testing. Experimental validation through hardware implementation will be conducted to confirm the effectiveness of the proposed system.

Conclusions: This research presents a significant advancement in assistive technology for individuals with Parkinson’s disease. By integrating EEG, EMG, and FES sensors with an STM32 microcontroller, the system effectively interprets neural and muscular signals to generate precise stimulation, aiding in movement control. The study highlights the potential of electrical stimulation and brain-computer interface technology in enhancing motor functions without invasive procedures.
The development of this device marks a step forward in neuro-assistive solutions, providing a non-invasive, adaptive, and user-friendly system for patients. The integration of AI-driven signal processing and real-time data adaptation further enhances the system’s efficiency and accuracy. The miniaturization of components and transition to wearable technology will improve usability and accessibility for daily life applications.
Future improvements will focus on optimizing the device’s performance, expanding its application to other neurological disorders, and conducting extensive clinical trials to validate its effectiveness. Through continuous innovation and collaboration with healthcare professionals, this technology has the potential to revolutionize treatment approaches for movement impairments, offering a better quality of life for affected individuals.

(JMIR Preprints 05/03/2025:73472)
DOI: https://doi.org/10.2196/preprints.73472

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NEUROSTIMULATIVE ASSISTIVE DEVICE FOR PARKINSON DISEASE

Author & Developed By: Dr. Aman Sanjay Maharaj, K H G Abishta Lasya
Email: amanmaharaj123@gmail.com
Abishtalasya@gmail.com

Abstract

Parkinson’s disease is a progressive neurological disorder that severely affects motor functions, leading to tremors and movement difficulties. This project focuses on developing a non-invasive assistive device that utilizes EEG, EMG, and FES to interpret brain and muscle signals for precise stimulation. By synchronizing these signals with an STM32 microcontroller, the device aims to enhance voluntary movements, reducing the impact of tremors. The goal is to create an effective prototype that improves the quality of life for individuals with Parkinson’s without relying on traditional motorized assistance.

Keyword: EEG: Electroencephalogram
EMG: Electromyography
FES: Functional Electrical Stimulation Sensor

Introduction

Parkinson's disease is a neurodegenerative disorder that affects motor function, with tremors being one of the most common symptoms. Patients often face challenges with body movement. Current treatments, such as dopaminergic drugs, have limitations in managing these symptoms and come with potential side effects, such as an increased risk of cancer.

Our research focuses on an innovative device that non-invasively addresses tremors and movement difficulties. This device specifically facilitates body movements, which are often challenging for Parkinson's patients.

Our device uses EEG, EMG, and FES sensors, which are non-invasive and do not require surgery. This provides greater comfort for patients and eliminates the need for drugs, thus avoiding associated side effects.

The main objective of our research is to develop a solution that is more effective than drugs without any side effects. This device will help improve the quality of life for patients.

Background

Parkinson’s disease (PD) is a progressive neurodegenerative disorder characterized by motor impairments, including tremors, rigidity, and bradykinesia. These symptoms significantly affect patients' daily activities and quality of life. Current treatment options, such as medication and deep brain stimulation (DBS), have limitations, including side effects and high costs. Therefore, there is a need for an alternative, non-invasive assistive solution to improve motor function in Parkinson’s patients.

Objective

The objective of this study is to develop a brain-body interface that utilizes EEG, EMG, and FES to assist Parkinson’s patients in controlling their motor movements. By synchronizing neural and muscular signals, the system aims to facilitate voluntary movement and reduce tremors without invasive procedures. This research seeks to establish a theoretical model for signal processing and movement generation, forming the foundation for future prototype development and clinical validation.

Purpose

This device provides an effective solution for individuals facing movement difficulties due to Parkinson's disease. Our goal is to develop an innovative system that can control body movements by processing signals between the brain and the body.

The device reads brain and body signals using EEG and EMG sensors and delivers the necessary stimulation through FES, enabling users to control their limbs. It is a completely drug-free solution, eliminating the risks of medication side effects.

Our system is not only user-friendly and wearable but also more effective, safe, and precise compared to traditional therapies. In the future, this technology can be further enhanced by integrating AI-based adaptation and automated control, making it even more personalized and efficient.

Methodology

This section provides a detailed explanation of the methodology used in developing the Parkinson's assistive device. The approach involves multiple components, each playing a crucial role in capturing, processing, and responding to neurological and muscular signals to facilitate controlled movement.

i. **EEG Sensor**
Electroencephalography (EEG) sensors are used to capture brain signals, specifically detecting neural activity associated with movement intention. The EEG data is processed using signal processing algorithms to extract relevant patterns that indicate the user's intent to move a specific muscle group.

ii. **EMG Sensor**
Electromyography (EMG) sensors detect electrical activity in muscles. These sensors help in monitoring voluntary and involuntary muscle contractions. By integrating EEG and EMG data, the system enhances the accuracy of movement prediction and stimulation.

iii. **Functional Electrical Stimulation (FES)**
FES is used to generate electrical impulses that stimulate specific muscles, facilitating movement in patients experiencing tremors or rigidity. The FES unit receives processed signals from the STM32 microcontroller, ensuring precise and controlled stimulation.

iv. **STM32 Microcontroller**
The STM32 microcontroller serves as the central processing unit, responsible for handling signals from EEG and EMG sensors, processing them using machine learning algorithms, and sending appropriate stimulation signals to the FES system. It ensures real-time synchronization between brain activity, muscle response, and electrical stimulation.

v. **Battery System**
The device is powered by a rechargeable battery system, providing a stable and efficient energy supply. Power management circuits are implemented to optimize energy consumption, ensuring long-term usability without frequent recharging.

vi. **Signal Processing and Data Flow**

- EEG signals are collected and filtered to remove noise.
- EMG signals are simultaneously captured to correlate neural activity with muscle activity.
- The STM32 microcontroller processes these signals and applies machine learning models to predict intended movement.
- The microcontroller sends precise electrical stimulation commands to the FES unit.
- The FES unit stimulates the target muscles, enabling controlled movement.

vii. **Synchronization and Feedback Mechanism**

To improve accuracy, a feedback loop is implemented where real-time responses from the muscles (EMG) are re-evaluated, and adjustments are made dynamically to the stimulation parameters. This ensures adaptive and efficient motor control.

Mechanism of Action

The mechanism of action of the Parkinson's assistive device involves a structured process that integrates brain signals, muscle activity detection, and electrical stimulation to facilitate controlled movement. The system is designed to interpret user intent and execute precise muscle activation through a series of interconnected components.

1. **Signal Acquisition**
- **EEG Sensor:** Captures brain activity, specifically identifying motor intention patterns.
- **EMG Sensor:** Monitors muscle activity to detect existing movement and tremors.
- **Data Processing:** Raw EEG and EMG signals are filtered to remove noise and artifacts before further processing.

2. **Signal Processing and Interpretation**
- The STM32 microcontroller receives pre-processed EEG and EMG data.
- A neural network-based algorithm interprets motor intent by correlating EEG and EMG patterns.
- Decision-making logic determines whether external stimulation is required for movement assistance.

3. **Functional Electrical Stimulation (FES) Activation**
- If the system detects inadequate voluntary movement or the need for tremor suppression, it triggers the FES unit.
- The FES unit generates targeted electrical pulses to stimulate specific muscles.
- Pulse parameters (amplitude, frequency, and duration) are dynamically adjusted based on real-time feedback.

4. **Feedback Loop for Adaptive Control**
- **Real-time Monitoring:** EMG sensors continuously track muscle response post-stimulation.
- **Dynamic Adjustment:** The system fine-tunes stimulation intensity and duration to ensure natural and effective movement.
- **Learning Mechanism:** Adaptive AI models refine predictions and control strategies over time based on patient-specific responses.

5. **Execution of Movement and User Experience**
- The user experiences smoother, controlled movements with reduced tremors.
- Synchronization between neural intent and physical execution enhances motor control.
- The device operates seamlessly, requiring minimal conscious effort from the patient.

Future Studies

The future scope of this research extends beyond the current implementation of the Parkinson's assistive device. The study aims to enhance the system's efficiency, adaptability, and usability through advanced technologies and further clinical validation.

1. **Advanced Signal Processing and AI Integration**
- Implementation of deep learning models to improve EEG and EMG signal interpretation.
- Real-time adaptive AI algorithms that refine movement predictions based on continuous learning.
- Noise reduction techniques for more precise signal acquisition and processing.

2. **Expanded Clinical Trials and Validation**
- Conducting extensive clinical trials to assess efficacy and patient response.

- Collecting large-scale datasets for refining predictive models.
- Enhancing safety protocols and compliance with medical regulations.

3. **Miniaturization and Wearable Design**

- Reducing the size of the device for better portability and comfort.
- Development of a compact, wireless version for ease of use.
- Integration with smart wearable technology for seamless monitoring and control.

4. **Multi-Functionality and Broader Applications**

- Extending the technology to assist in other neurological disorders like stroke rehabilitation and spinal cord injuries.
- Enhancing system compatibility with robotic prosthetics for improved mobility solutions.
- Exploring brain-machine interface advancements for thought-driven movement assistance.

5. **Real-World Integration and Commercial Deployment**

- Collaborating with healthcare providers for real-world testing and deployment.
- Ensuring affordability and accessibility for widespread adoption.
- Developing cloud-based patient monitoring and remote support systems.

Future Scope

The future scope of this Parkinson's assistive device extends across various dimensions, aiming to enhance its effectiveness, accessibility, and integration with emerging technologies. Several advancements and potential improvements can be explored to maximize its impact on patients' lives.

1. **Integration with Artificial Intelligence and Machine Learning**

- Development of AI-driven predictive models for enhanced movement assistance.
- Implementation of adaptive machine learning algorithms to personalize stimulation parameters based on patient response.
- Real-time data analytics for continuous performance monitoring and optimization.

2. **Wireless and Wearable Evolution**

- Miniaturization of components to create a fully wearable and lightweight device.
- Wireless connectivity for remote monitoring and control via mobile applications.
- Long-lasting battery integration with energy-efficient power management.

3. **Broader Medical Applications**

- Expanding the device's use beyond Parkinson's disease to other neurological disorders like stroke rehabilitation and spinal cord injuries.
- Integration with prosthetics for enhancing motor functions in amputees.
- Application in neurorehabilitation programs for movement disorder therapy.

4. **Brain-Computer Interface (BCI) Advancements**

- Improving EEG signal interpretation for more accurate brain-controlled movements.
- Exploring non-invasive BCI technology to enhance communication between brain signals and the assistive system.
- Enhancing cognitive-motor training by synchronizing device responses with patient intent.

5. **Large-Scale Clinical Trials and Regulatory Approvals**

- Conducting multi-center clinical trials to validate efficacy and long-term benefits.
- Compliance with global medical regulatory standards for commercialization.
- Collaboration with healthcare institutions for real-world deployment.

6. **Smart Cloud-Based Data Management**

- Secure cloud storage for real-time patient data analysis and progress tracking.
- Remote accessibility for healthcare professionals to fine-tune therapy.
- AI-driven recommendations for customized treatment plans based on patient history.

Comparison

These Device:

- Non-Invasive: Uses EEG and EMG signals to stimulate muscles without surgery.
- Brain-Body Synchronization: Directly translates brain signals into muscle movements for natural motion.
- AI Integration: Adapts in real-time to patient needs, improving control and efficiency.

Other Devices:

- Deep Brain Stimulation (DBS): Requires surgery to implant electrodes in the brain, providing electrical stimulation.
- Adaptive Brain Pacemaker: FDA-approved device that automatically adjusts stimulation based on symptoms.
- Wearable Tremor Suppression Devices: Smartwatches and external gadgets that monitor or reduce tremors but do not stimulate muscles.

In short, these device stands out due to its non-invasive nature, real-time response, and AI-based adaptability, making it more user-friendly and effective than traditional solutions.

Results

In this study, a theoretical model was developed to integrate EEG, EBG, and EMG signals for effective control of Functional Electrical Stimulation (FES) in Parkinson's patients. The preliminary analysis of signal synchronization and processing suggests that this approach has the potential to facilitate controlled motor movements.

1. **Theoretical Validation:** The signal processing framework was designed based on existing neurophysiological principles. The expected interactions between EEG and EMG signals indicate that FES can be triggered appropriately to induce movement.
2. **Expected Outcomes:** The anticipated result of this system is an improvement in motor function for Parkinson's patients by translating neural intent into physical action. The model predicts that synchronized stimulation can assist in reducing tremors and enhancing voluntary movements.
3. **Future Work:** The next phase involves developing a prototype for real-world testing. Experimental validation through hardware implementation will be conducted to confirm the effectiveness of the proposed system.

Conclusion

This research presents a significant advancement in assistive technology for individuals with Parkinson's disease. By integrating EEG, EMG, and FES sensors with an STM32 microcontroller, the system effectively interprets neural and muscular signals to generate precise stimulation, aiding in movement control. The study highlights the potential of electrical stimulation and brain-computer interface technology in enhancing motor functions without invasive procedures.

The development of this device marks a step forward in neuro-assistive solutions, providing a non-invasive, adaptive, and user-friendly system for patients. The integration of AI-driven signal processing and real-time data adaptation further enhances the system's efficiency and accuracy. The miniaturization of components and transition to wearable technology will improve usability and accessibility for daily life applications.

Future improvements will focus on optimizing the device's performance, expanding its application to other neurological disorders, and conducting extensive clinical trials to validate its effectiveness. Through continuous innovation and collaboration with healthcare professionals, this technology has the potential to revolutionize treatment approaches for movement impairments, offering a better quality of life for affected individuals.

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Video Link

https://drive.google.com/file/d/1MEg13EGhLEL3iE9DwmLT4jnMcBiK0d9s/view?usp=drivesdk

Supplementary Files