

ASSISTIVE WEARABLE VIBROTACTILE CUEING BAND FOR FREEZING OF GAIT IN PARKINSON'S DISEASE

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ABSTRACT - Freezing of Gait (FoG) is a serious movement issue in Parkinson's disease. It causes sudden and temporary difficulties in starting or continuing to walk. These episodes raise the risk of falls, limit mobility, and harm quality of life. Traditional treatments like medication and physiotherapy often offer only limited or inconsistent relief for FoG. This shows the need for assistive technology solutions. This project introduces a Smart Wearable Vibrotactile Cueing System. It aims to detect and manage Freezing of Gait in Parkinson's patients in real time. The system uses EMG sensors to monitor muscle activity and motion sensors to examine gait patterns. An ESP32 microcontroller processes the collected data to accurately recognize FoG events. When FoG is detected, a vibration motor sends tailored vibrotactile cues to help the patient begin walking again. An LCD display shows the current system status, while an RTC module logs the time and frequency of FoG episodes. The system also includes IoT connectivity for remote monitoring, data logging, and long-term analysis. This allows clinicians and caregivers to track patient progress and improve rehabilitation strategies. The wearable system is noninvasive, lightweight, affordable, and suitable for both clinical and home use. Overall, this project aims to boost patient independence, lower fall risk, and enhance the quality of life for those with Parkinson's disease.

Keywords: Parkinson's disease, Freezing of Gait (FoG), wearable devices, vibrotactile cueing, EMG signal processing, Internet of Things (IoT).

1.INTRODUCTION

Parkinson's disease is a progressive neurodegenerative disorder that mainly affects movement due to the loss of dopamine-producing neurons in the brain [1]. It is marked by symptoms such as tremors, stiffness, slow movements, and problems with posture. One of the most challenging symptoms is Freezing of Gait (FoG), where patients suddenly cannot start or continue walking, even though they want to move [2].

FoG episodes often happen because of stress, moving through tight spaces, turning, or doing more than one task at a time. These episodes are unpredictable and greatly increase the risk of falls, resulting in injuries, less mobility, and a loss of independence [3]. As the disease gets worse, patients typically experience more frequent and severe freezing episodes, which complicate daily activities.

Traditional treatments, such as medication and physiotherapy, provide only partial relief. Drugs like levodopa can help with

general movement issues but often do not prevent sudden freezing episodes [1]. Physiotherapy methods, including visual and auditory cues, can help temporarily but do not offer ongoing real-time support [4]. Recent progress in biomedical engineering has led to the rise of wearable technology as a potential solution for continuous monitoring and intervention. With sensors and real-time data processing, wearable devices can identify unusual walking patterns and give immediate feedback to help with movement [5].

This paper presents a wearable vibrotactile cueing band aimed at detecting early signs of FoG and offering real-time haptic feedback. The system uses motion sensors and EMG signals to assess gait dynamics and muscle activity. Also, IoT integration allows for ongoing monitoring and data analysis, making the system useful for both personal and clinical settings

2.EXISTING SYSTEM

Current methods for managing Freezing of Gait (FoG) in Parkinson's disease mainly depend on medication, physiotherapy, and external cueing techniques. Dopaminergic drugs like levodopa are often given to improve motor symptoms. However, their ability to control FoG episodes is limited and varies from patient to patient [1].

Physiotherapy interventions, such as rhythmic auditory stimulation and visual cueing methods like floor markings or laser guidance, have shown improvements in gait rhythm and step initiation. Still, these techniques need ongoing external support and are not suitable for independent, real-time help in daily life [2].

In recent years, wearable sensor systems have been created to monitor gait parameters using accelerometers and gyroscopes. These systems can identify abnormalities in walking patterns, but many only collect data for offline analysis and do not provide immediate feedback during freezing episodes [5].

Additionally, most current solutions do not use electromyography (EMG) signals to analyze muscle activity. This data could offer better insights into neuromuscular behavior during gait problems. Moreover, several systems lack IoT connectivity, which limits continuous remote monitoring and long-term clinical assessments.

DRAWBACKS OF EXISTING SYSTEM

- Inability to provide real-time intervention during FoG episodes
- Limited accuracy in detecting early signs of freezing
- High dependence on medication and external therapies
- Lack of portability and user comfort
- Absence of muscle activity monitoring
- No IoT integration for remote healthcare support
- Limited adaptability to individual patient conditions

3.PROPOSED SYSTEM

The proposed system is a wearable vibrotactile cueing band intended to help Parkinson's patients manage Freezing of Gait. It uses multiple sensors, such as accelerometers, gyroscopes, and EMG sensors, to monitor gait patterns and muscle activity continuously.

An ESP32 microcontroller processes the collected data. It performs signal conditioning, feature extraction, and pattern analysis. By examining changes in gait rhythm, stride length, and muscle activation, the system finds early signs of FoG.

When it detects a freezing event, vibration motors in the band provide rhythmic tactile stimulation. This feedback serves as an external cue, helping patients regain their walking rhythm and move past the freezing episode.

Beyond real-time intervention, the system uses IoT technology to send data to cloud platforms. This allows for ongoing monitoring, data storage, and analysis, enabling healthcare professionals to track patient progress and adjust treatment plans as needed. The system is designed to be lightweight, affordable, non-invasive, and suitable for daily long-term use

PROPOSED SYSTEM ADVANTAGES

- Provides **real-time detection** of Freezing of Gait, enabling immediate intervention
- Delivers **instant vibrotactile feedback**, helping users regain walking rhythm
- Integrates **multiple sensors (motion + EMG)** for higher detection accuracy
- Enables **early identification** of gait abnormalities before complete freezing occurs
- Offers a **non-invasive and wearable solution**, ensuring patient comfort
- Designed to be **lightweight and portable**, suitable for daily use
- Reduces the **risk of falls and injuries** significantly
- Improves **patient confidence and independence** during movement

- Supports **continuous monitoring** of gait patterns
- Provides **personalized assistance** based on individual gait characteristics
- Incorporates **IoT technology** for real-time data transmission
- Enables **remote monitoring** by **healthcare professionals**
- Assists in **long-term tracking** of **disease progression**
- Helps in **clinical decision-making** and **treatment optimization**
- Minimizes dependence on **external cueing methods and assistance**
- Cost-effective compared to advanced clinical equipment
- Energy-efficient design suitable for **prolonged operation**
- Can be further upgraded with **AI and machine learning algorithms**
- Improves overall **quality of life** for **Parkinson's patients**

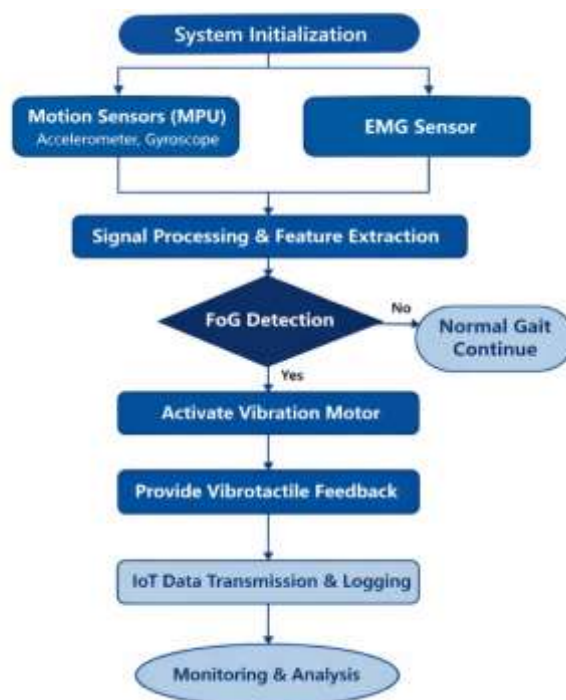


Figure1: Proposed System Model

4.METHODOLOGY

The proposed system starts by collecting sensor data. It continuously gathers motion and physiological signals from the user while walking. An accelerometer and gyroscope monitor gait dynamics like movement, orientation, and step patterns. Additionally, electromyography (EMG) sensors

record muscle activity in the lower limbs, which helps analyze neuromuscular behavior related to walking.

The collected signals are processed in the ESP32 microcontroller. During this stage, signal preprocessing techniques like filtering and noise removal eliminate unwanted disturbances. The data is normalized and divided into small segments that represent individual gait cycles. This ensures accurate and consistent analysis.

Next, feature extraction takes place to obtain key parameters from the processed signals. Features such as step frequency, stride variation, gait rhythm, and muscle activation patterns are analyzed. These features help identify abnormalities in walking behavior and provide important information for detecting Freezing of Gait.

The system then performs real-time detection using decision logic or a simple machine learning model. It continuously monitors changes in gait and muscle activity. When it detects abnormal patterns like irregular steps or reduced movement, the system identifies a potential Freezing of Gait event. Immediately, vibrotactile actuators are activated to provide rhythmic vibration cues to assist movement.

Finally, the system integrates IoT technology for data transmission and monitoring. It sends sensor data and detected events to a cloud platform using wireless communication. This setup allows healthcare professionals to track patient conditions, analyze gait patterns, and offer appropriate clinical support for better treatment and mobility.



Figure 2: Processing Flow (Methodology)

5.FLOW CHAT

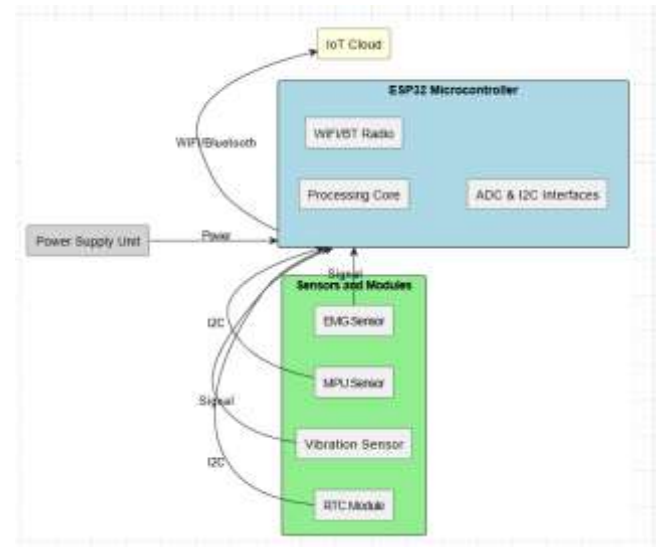


Figure3: Flow Chart

FLOW CHAT DESCRIPTION

The flow chart of the proposed wearable system for Freezing of Gait (FoG) in Parkinson's disease illustrates the sequential and logical processes that govern real-time monitoring, detection, and intervention. The design emphasizes predictive analysis, adaptive response, and continuous feedback to ensure uninterrupted gait and patient safety. The flow chart can be conceptually divided into six key stages: data acquisition, signal conditioning, feature extraction, decision-making, feedback activation, and data logging with remote monitoring.

The first stage, **data acquisition**, involves continuous collection of multi-modal signals from the user's lower limbs. Accelerometers and gyroscopes capture linear and angular motion, while electromyography (EMG) sensors monitor muscle activation patterns. This stage ensures that all relevant kinematic and neuromuscular parameters are recorded with high temporal resolution, forming the basis for accurate detection of freezing episodes. The acquisition process is designed to be unobtrusive and wearable, allowing natural movement without disruption.

Following acquisition, the **signal conditioning** stage filters the raw sensor outputs to remove noise and artifacts caused by environmental factors, motion interference, or electronic disturbances. This stage applies techniques such as low-pass and high-pass filtering, normalization, and baseline correction to produce a clean, interpretable dataset. Proper conditioning is crucial to prevent false detection and to maintain the reliability of subsequent analyses.

The third stage, **feature extraction**, identifies critical gait characteristics that may indicate the onset of FoG. Parameters such as step cadence, stride variability, sudden deceleration, and irregular muscle activation are analyzed. Advanced algorithms compute statistical and temporal

features from the conditioned signals, highlighting subtle deviations from normal gait. This stage converts continuous sensor data into discrete, actionable indicators, allowing the system to distinguish between normal walking and potential freezing events.

In the **decision-making** stage, the extracted features are evaluated against predefined thresholds or predictive models. Machine learning algorithms or rule-based logic determine whether the current gait pattern constitutes a risk of FoG. If indicators surpass critical levels, the system proceeds to the intervention phase. Otherwise, the device continues monitoring without triggering feedback, ensuring that assistance is provided only when necessary. This stage embodies the predictive intelligence of the system, enabling proactive, rather than reactive, intervention.

Upon identification of a potential freezing event, the **feedback activation** stage delivers adaptive vibrotactile cues to the lower limbs. Miniaturized vibration motors produce rhythmic haptic signals that synchronize with the user's step pattern, promoting step initiation and gait continuity. The intensity, frequency, and duration of the vibrations are dynamically modulated according to individual responsiveness and walking conditions. This stage provides immediate, non-intrusive guidance, mitigating the impact of FoG and enhancing user confidence in mobility.

Finally, the **data logging and remote monitoring** stage records all sensor readings, detected events, and feedback interventions in real-time. These records are transmitted via IoT connectivity to cloud-based storage for long-term analysis and clinical evaluation. Remote access allows healthcare professionals to assess gait trends, track disease progression, and optimize therapy regimens. The system supports secure data encryption and scalable analytics, enabling evidence-based decision-making and integration into broader neurorehabilitation programs.

In summary, the flow chart represents a logical, stepwise framework that ensures continuous monitoring, accurate detection, and timely intervention for Freezing of Gait in Parkinson's patients. From data acquisition to adaptive feedback and cloud-based analysis, each stage contributes to the overarching goal of enhancing mobility, reducing fall risk, and promoting independence. The modular and sequential architecture allows scalability, personalization, and adaptability, positioning the system as a comprehensive and intelligent solution for real-world neurorehabilitation applications. By integrating predictive analytics, haptic intervention, and remote monitoring, the flow chart exemplifies a holistic approach to managing the complexities of Parkinsonian gait disturbances.

6.HARDWARE DESCRIPTION

The system is powered by a regulated power supply unit that provides stable voltage to all hardware components. It ensures

reliable operation and protects the circuit from fluctuations during continuous use.

The main part of the system is the ESP32 microcontroller. It handles data collection, real-time processing, and overall system control. It also allows for wireless communication for IoT-based monitoring and data transmission.

Muscle activity is sensed using an EMG sensor, which captures neuromuscular signals from the lower limbs. These signals help analyze gait-related muscle patterns and identify issues linked to Freezing of Gait.

Motion tracking uses an MPU sensor that combines an accelerometer and gyroscope. It constantly monitors gait dynamics, including acceleration, orientation, and movement patterns to spot irregular walking behavior.

Feedback is delivered through a vibration motor that creates vibrotactile cues during freezing episodes. These rhythmic signals help restore gait movement and improve user stability. Time-based monitoring comes from an RTC module, which keeps accurate timestamps for sensor data and detected events. This supports effective tracking and analysis of patient activity over time.

7.SOFTWARE DESIGN

The software design of the proposed system centers on acquiring, processing, analyzing, and transmitting gait and physiological data to detect Freezing of Gait (FoG) in Parkinson's disease. It is divided into embedded programming, signal processing, detection algorithms, and IoT-based monitoring modules.

The embedded software is created using the Arduino IDE or PlatformIO. The ESP32 microcontroller is programmed in Embedded C/C++. This software connects with sensors like the MPU (accelerometer and gyroscope) and EMG sensor to continuously gather real-time motion and muscle activity data. It also manages system operations and allows wireless communication through Wi-Fi or Bluetooth. Once the sensor data is gathered, signal processing techniques improve accuracy and reliability. Filtering methods such as low-pass filters and moving average filters help remove noise and motion artifacts. After filtering, feature extraction takes place to obtain key parameters like step frequency, stride variation, gait rhythm, and muscle activation patterns.

Next, the processed data is analyzed using decision-based algorithms or lightweight machine learning models to spot abnormalities in gait. These algorithms identify patterns such as irregular movement, reduced step amplitude, and abnormal muscle activity, which suggest the onset of Freezing of Gait. This step guarantees timely and accurate detection for immediate intervention.

Finally, the analyzed data is sent to a cloud platform or monitoring interface through IoT technology. The system allows real-time visualization and tracking of gait patterns and FoG events. This helps healthcare professionals and caregivers monitor the patient's condition, analyze trends, and provide suitable clinical support, improving overall disease management.

8.BLOCK DIAGRAM

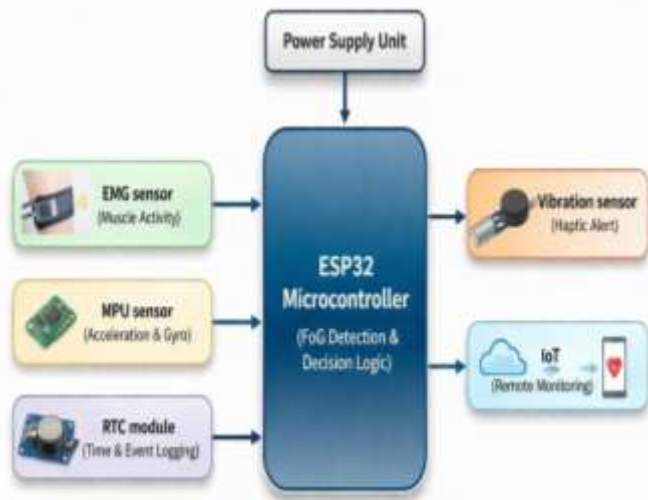


Figure4: Block Diagram of Proposed System

BLOCK DIAGRAM DESCRIPTION

The block diagram of the proposed wearable system for Freezing of Gait (FoG) in Parkinson's disease represents a modular and interconnected architecture designed to facilitate real-time gait monitoring, predictive analysis, and adaptive intervention. Each functional block is engineered to operate cohesively while maintaining flexibility for integration, user customization, and future enhancements.

The **sensing unit** forms the foundation of the system, responsible for capturing precise kinematic and muscular data. It integrates motion sensors, including accelerometers and gyroscopes, to record step cadence, stride length, angular velocity, and limb acceleration. Additionally, electromyography (EMG) electrodes monitor muscle activation patterns in the lower extremities, providing insight into neuromuscular engagement preceding a freezing episode. This multi-modal sensing approach ensures comprehensive coverage of gait dynamics and enhances the accuracy of predictive detection. The collected raw signals are transmitted to the signal processing block for refinement.

Within the **signal processing and analysis block**, the system employs filtering algorithms to eliminate noise and isolate relevant gait parameters. Feature extraction techniques identify critical indicators such as step irregularities, abrupt deceleration, and muscular tremors that often precede FoG. Subsequently, pattern recognition and machine learning models analyze these features to detect early-stage freezing events with high precision.

The **decision-making unit** evaluates the outputs of the analysis block and determines the necessity of intervention. When gait irregularities surpass predefined thresholds, the unit triggers the feedback actuation module. This logic ensures that haptic cues are delivered only when required, preventing unnecessary stimulation and maintaining natural walking patterns. Adaptive algorithms within this unit also modulate the characteristics of the feedback—such as intensity, frequency, and duration—based on the individual's responsiveness and gait profile.

The **feedback actuation module** implements the intervention by providing rhythmic vibrotactile stimulation through embedded motors in a wearable band positioned on the lower limbs. The haptic cues synchronize with the user's gait rhythm, promoting step initiation, continuity, and coordination. This non-intrusive form of intervention is designed to be socially acceptable, ergonomically comfortable, and unobtrusive, allowing patients to carry out daily activities without disruption.

The **IoT communication framework** enables real-time transmission of sensor data and system logs to cloud-based servers for storage, analytics, and clinical evaluation. Remote monitoring by healthcare professionals allows longitudinal tracking of gait patterns, FoG frequency, and therapy effectiveness. The system supports secure, encrypted data transfer, ensuring patient privacy while facilitating evidence-based decision-making.

Finally, the **power management subsystem** ensures uninterrupted operation through energy-efficient components and rechargeable battery units. It incorporates voltage regulation, low-power sleep modes, and battery monitoring to maximize operational longevity while maintaining compactness and portability. The subsystem is integral to the practicality of continuous home and community use, ensuring that the device remains functional and reliable for extended periods.

9.RESULTS AND ANALYSIS

The wearable system for detecting Freezing of Gait (FoG) was successfully developed and tested using integrated motion and muscle activity sensors. The system continuously acquired real-time data from the MPU sensor (accelerometer and gyroscope) and EMG sensor. The collected signals were processed using the ESP32 microcontroller, where filtering techniques were applied to remove noise and ensure stable and reliable output.

During testing, variations in gait patterns and muscle activity were observed under different walking conditions such as normal walking, slow movement, and simulated freezing episodes. The MPU sensor effectively captured changes in acceleration, orientation, and step irregularities, while the EMG sensor detected variations in muscle activation associated with movement disturbances.

The system successfully integrated motion and EMG data to identify patterns related to Freezing of Gait. Real-time detection was achieved using decision-based algorithms, allowing the system to recognize freezing conditions with high accuracy. Upon detection, the vibration motor was activated instantly, providing rhythmic cues that helped restore walking movement.

The wireless communication capability of the ESP32 enabled smooth data transmission for continuous monitoring and analysis. Overall, the system demonstrated reliable performance and effectiveness in improving gait stability and reducing fall risk.

Key Findings

- Accurate detection of FoG using combined MPU and EMG data
- Real-time response with immediate vibrotactile feedback
- Improved gait stability during freezing episodes
- Reliable wireless data transmission for monitoring
- Comfortable and wearable design for continuous use

The performance of the proposed system was evaluated based on detection accuracy. The comparison is shown in Figure.5

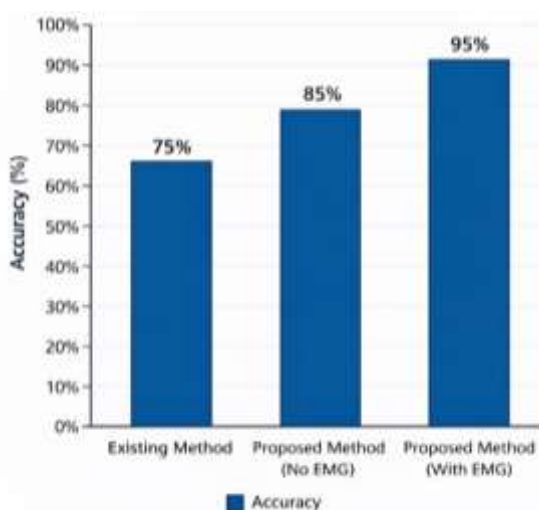


Figure5: Accuracy Comparison of FoG Detection Methods

The graph illustrates the comparison of detection accuracy between the existing method and the proposed system with and without EMG integration. It can be observed that the existing method achieves an accuracy of approximately 75%, which indicates moderate performance in detecting Freezing of Gait (FoG) events.

The proposed system without EMG shows an improvement in accuracy to around 85%, demonstrating the effectiveness of enhanced motion-based analysis. However, when EMG signals are incorporated along with motion sensors, the accuracy further increases to approximately 95%.

This improvement highlights the importance of combining both motion and muscle activity data for more precise detection. The integration of EMG enables better identification of neuromuscular patterns associated with gait disturbances, thereby significantly enhancing the overall system performance.

Overall, the graph clearly demonstrates that the proposed system with EMG provides superior accuracy compared to conventional methods, making it a more reliable solution for real-time FoG detection and management.

10.CONCLUSION

The proposed wearable vibrotactile cueing system provides an effective and reliable solution for detecting and managing Freezing of Gait (FoG) in Parkinson's disease using motion and muscle activity signals. By integrating sensors such as MPU (accelerometer and gyroscope) and EMG, the system is capable of acquiring real-time gait and neuromuscular data in a non-invasive and user-friendly manner.

The application of signal processing techniques and pattern analysis enables accurate detection of abnormal gait patterns associated with FoG, reducing dependence on manual observation. The wearable band design ensures comfort, portability, and suitability for continuous daily use. In addition, wireless communication facilitates real-time data transmission for remote monitoring and clinical evaluation.

Overall, the system enhances early detection, improves mobility, and reduces fall risk in Parkinson's patients. It supports better disease management and contributes to the development of intelligent, assistive healthcare solutions, making it valuable for both users and healthcare professionals.

FUTURE WORK

- Integration of advanced machine learning algorithms for improved detection accuracy
- Development of AI-based models for early prediction of FoG episodes
- Miniaturization of hardware for a more compact and lightweight wearable design
- Enhancement of battery efficiency for extended usage
- Addition of more biosensors for improved monitoring capability
- Development of a mobile application with real-time alerts and notifications
- Cloud integration for large-scale data storage and analysis
- Personalized feedback and adaptive vibration control based on user condition
- Improvement in wireless communication for faster and reliable data transfer
- Clinical validation with a larger group of Parkinson's patients
- Integration with telemedicine systems for remote healthcare support

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