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Wearable Sensor Based Gait Analysis and Robotic Exoskeleton Control for Parkinson's Patients

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INTRODUCTION

Gait disorders are key indicators of neurological conditions like Parkinson's disease, significantly impacting patients' quality of life. Despite the importance of detecting and classifying gait issues for effective treatment, there is no standardized gait analysis system. Wearable sensors offer a promising solution by capturing walking dynamics continuously, enabling both analysis and intervention through real-time monitoring. Additionally, soft robotic exoskeletons can improve gait by applying corrective forces, but optimal therapeutic effects require disorder-specific control and real-time feedback.[1]

This study presents a real-time gait analysis system for Parkinson's patients, using a combination of physiological, kinetic, and kinematic wearable sensors. Strategically placed on key muscle groups, these sensors collect comprehensive data on muscle activity, movement patterns, weight distribution, and balance. Sensor data is wirelessly transmitted to a server for processing by a central microcontroller, supporting the development of adaptive control algorithms. Integration of ML techniques allows the system to learn from user data, optimizing therapy over time.

MATERIALS AND METHODS

In this study, physiological, kinematic and kinetic data were collected in real time from the user's leg. Different types of sensors were placed appropriately on muscle groups and the foot. Physiological and kinematic sensor data were collected via a wireless device attached to the user's leg with a belt and processed by a central MCU. Kinetic data was collected by load cells placed on the sole of the shoe. The data was transferred in real time to a server and then converted into a database format suitable for machine learning.

Figure 1. Photographs of the basic devices we produced within the scope of the project (left) The main device connected to the foot, the EMG cables coming out of it are visible. (mid) Measuring slippers with force sensitive resistors placed underneath, which we use for ground reaction force measurement. (right) PCB that we produced

Physiological Metrics

We have designed and produced low-cost EMG singnal acquisiton hardware in accordance with our requirements and integrated it into your wearable device. This system, which will be used to obtain physiological data; signal conditioning circuit, Power distribution circuit, analog to digital converter will be examined in three parts. The summary diagram of the system is shown in Figure 2.

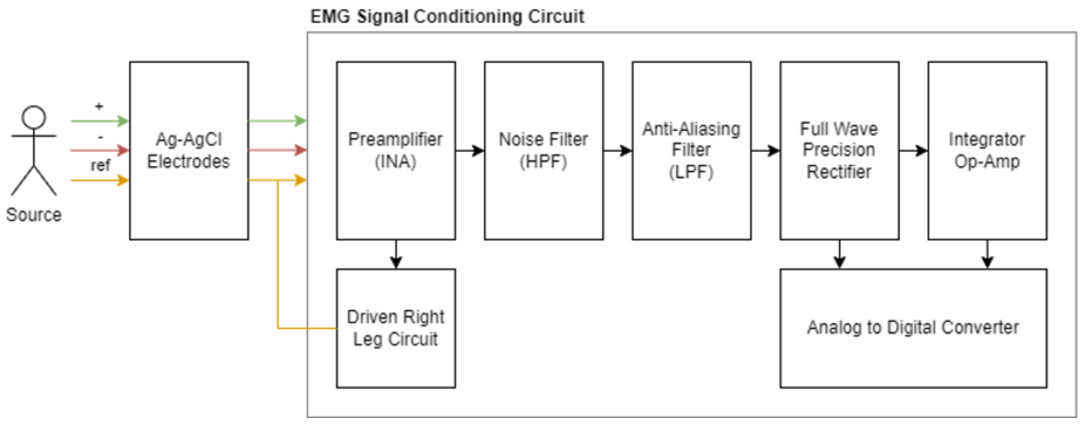

Figure 2. Summary diagram for EMG signal conditioning circuit and components.

Kinetic Metrics

In our system, we used half-bridge load cells capable of measuring up to 500N as force-sensitive resistors (FSRs). Four load cell transducers, were utilized. These load cells have a sensitivity of 2mV/V and are powered by an excita-tion voltage (VE) of ±9V, resulting in a signal output of 19mV under maximum load. To ensure accurate digitization of the signal, it must be amplified and subjected to several signal processing stages. The summary diagram of the system is shown in the Figure 3.

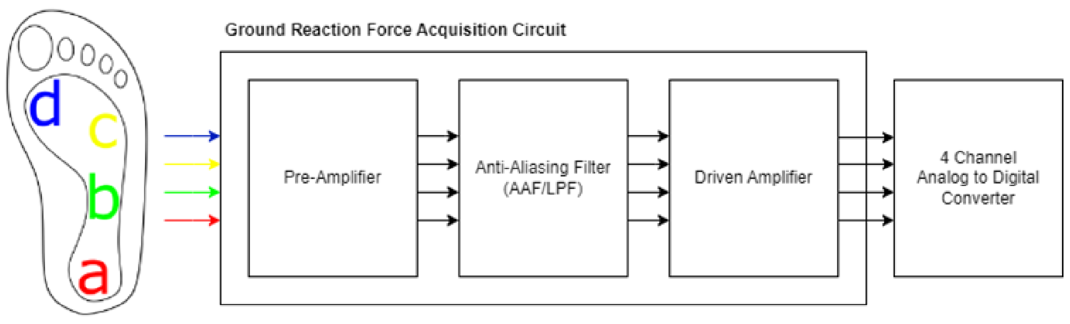

Figure 3. Summary diagram for GRF acquisition circuit

Kinematic Metrics

For the kinetic data we aim to obtain in addition to physiological and mechanical data, IMU (inertial measurement unit) sensors were placed on three regions of the leg: femoral, crural, and pedal. These sensors collect real-time accelerometer and gyroscope data. We selected the MPU6050 IMU module (Invensense, USA). The data are fused using a complementary filter and converted into roll and pitch values. Subsequently, the data from the three sensors are analyzed using basic mathematical equations to calculate joint angles between the limbs. This data is then used for 3D structural construction in MATLAB.

RESULTS

For the EMG, experimental setup was designed to observe voluntary muscle contractions, and tetanic muscle contraction detection was successfully achieved. The results indicate that the raw EMG results provide a favorable out-come for observing phasic muscle contraction activities occurring within one second. Upon examining all these results, it is demonstrated that we have a circuit capable of capturing physiological muscle signals in the range of 24-400 Hz at a sampling rate of 860 SPS. The total resolution is 45 nV, with the calculated lowest real sensitivity being 1.5 µV with a 5-bit uncertainty. The baseline noise is below 15 µVrms. The utilized DRL and in-strumentation amplifiers, when used in conjunction, offer a CMRR greater than 110 dB as per their design.

As shown in Figure 4, ground reaction force (GRF) was calculated from the data obtained from the sensors, and the center of pressure (CoP) was determined.

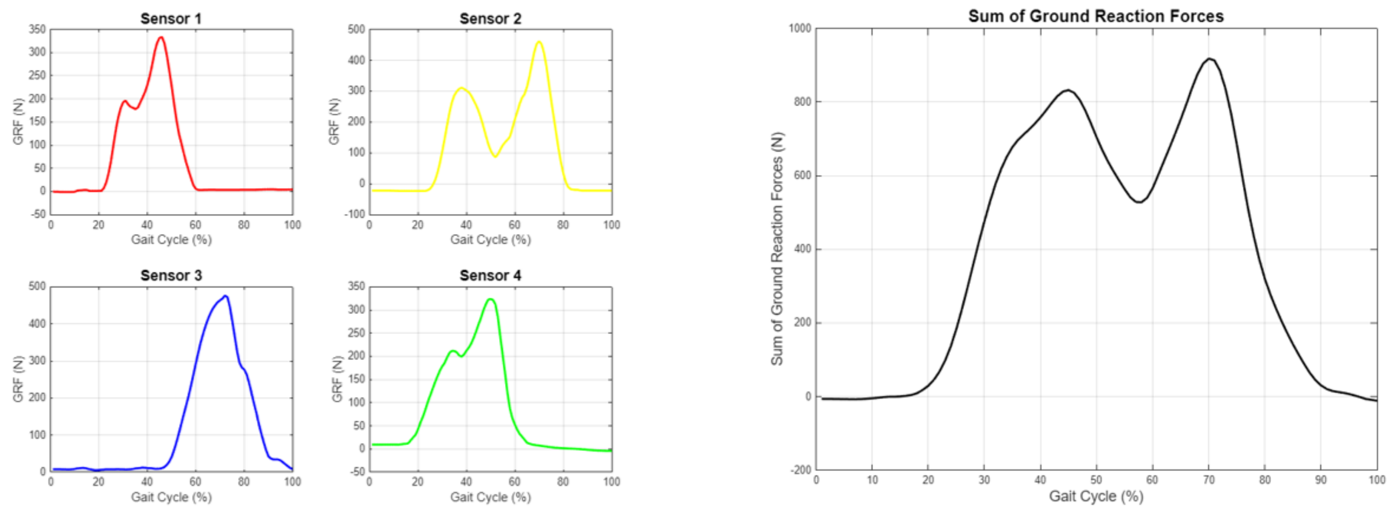

Figure 4. Ground Reaction Force Measurement Graphs for One Step. (a) Separate evaluation of data from four different sensors. (b) Resultant GRF obtained by combining sensor data.

Kinematic data were collected through the inertial sensors and combined in real time using a complementary filter. The 3D structural modeling created in MATLAB visually matches the actual test data. The measurement sensitivity of the gyroscope data obtained from the IMU is specified as ±250 °/s with a sensitivity of 131 LSB/°/s. The sensitivity for acceleration measurements is set at ±2g with a value of 16384 LSB/g. These sensitivy will enable a more comprehensive analysis by aligning them with physiological data.

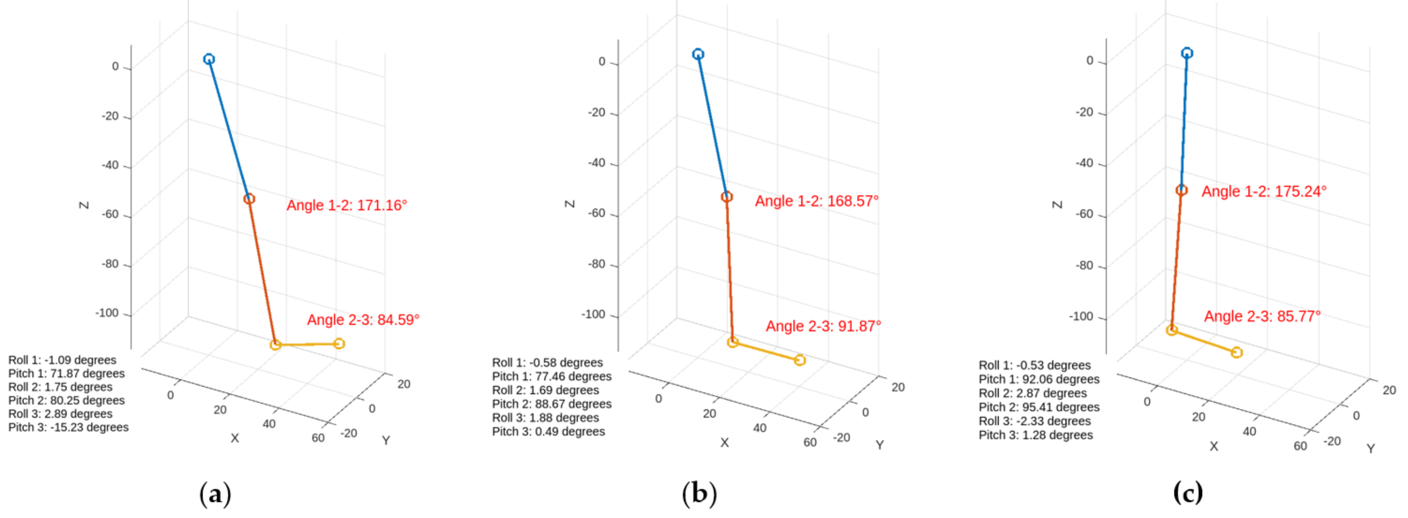

Figure 5. Visualization of Inertial Data During Walking. The figures display the angles between joints and orientation information. (a) Heel strike, (b) Foot flat, (c) Midstance

DISSCUSSION

This study presents a real-time gait analysis system using wearable sensors to control soft body exoskeletons for patients with gait disorders. Sensors positioned on key muscle groups capture physiological, kinetic, and kinematic data. EMG sensors track muscle activity, GRF measurements reveal foot pressure distribution, and inertial sensors generate 3D models of movement, aligning with test data. These results validate the system's capability to deliver real-time feedback, with future ML integration offering personalized therapy for enhanced outcomes.

References

[1] J.; Nuno Magalhães; Santos C.P. Pinheiro, C.; Figueiredo.
Wearable biofeedback improves human-robot compliance during ankle-foot exoskeleton-assisted gait training: A pre-post controlled study in healthy participants, sensors, 2020, 20 5876–5876.

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