INNOVATIVE WEARABLE ROBOTICS FOR ENHANCING LOWER LIMB MOBILITY AND FUNCTION

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Introduction

Wearable robotics provide an effective approach to support lower limb mobility in individuals with movement impairments. By using EMG sensors to detect muscle signals and IMUs to track motion, motorized assistance can be delivered in real time. An STM32-based control system processes these inputs to drive actuators smoothly. The design prioritizes lightweight structure and user comfort. The goal is to enhance natural movement and promote independent mobility.

Fig.1: Persons with mobility issues

Problem Statement

- Many individuals, particularly those over 60, face significant mobility challenges.
- These challenges often lead to increased dependency.
- Existing mobility devices are frequently expensive.
- They are also often confined to clinical settings,
- Limiting accessibility for independent living.

Objectives

The objectives of this project are to

- Implement process control for data acquisition & precise limb movement.
- Design CAD model for wearable device & mechanical frame.
- Integrate gear motors & sensors (EMG, IMU).
- Construct effective mechanical structure (frame & joints).

Composed Approach

To address these issues, this project presents an innovative wearable robotic system that assists elderly individuals with sit-to-stand, walking, and balance support. It uses high-torque gear motors at the hip and knee joints, controlled by the STM32 NUCLEO F103RB microcontroller. The system processes signals from EMG sensors to detect muscle activity and IMU sensors to track joint orientation. Based on this data, it provides real-time motor control for smooth and responsive movement. For users with weak muscle signals, predefined motion profiles ensure safe operation. This lightweight, affordable device is suitable for daily use, promoting independence outside clinical environments

Block diagram

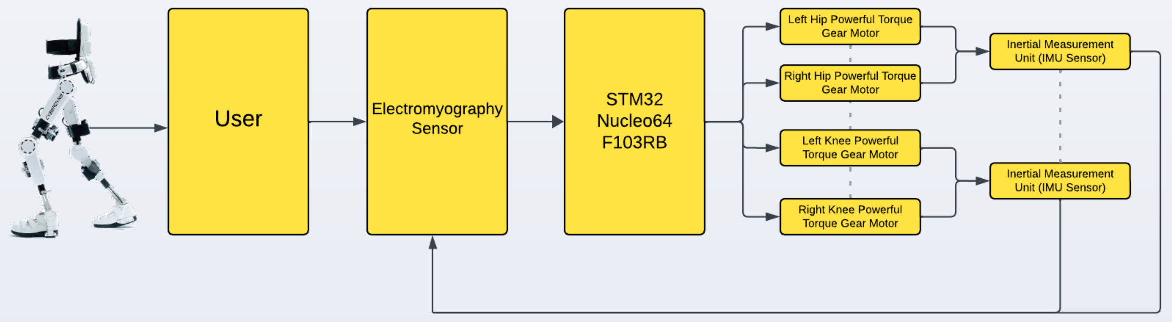

Fig. 2: Block Diagram

Flowchart

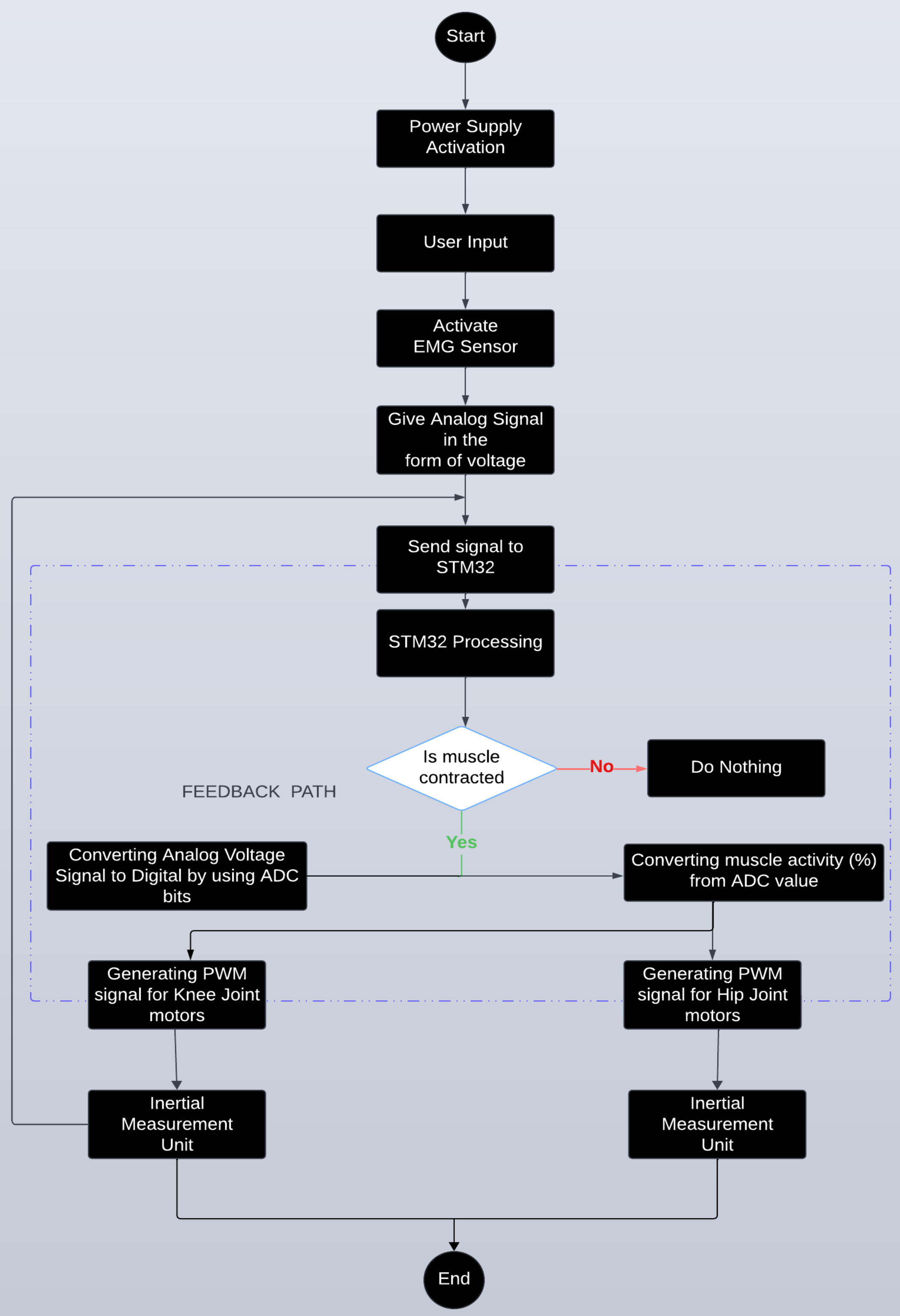

Fig. 3 Flowchart

System Architecture

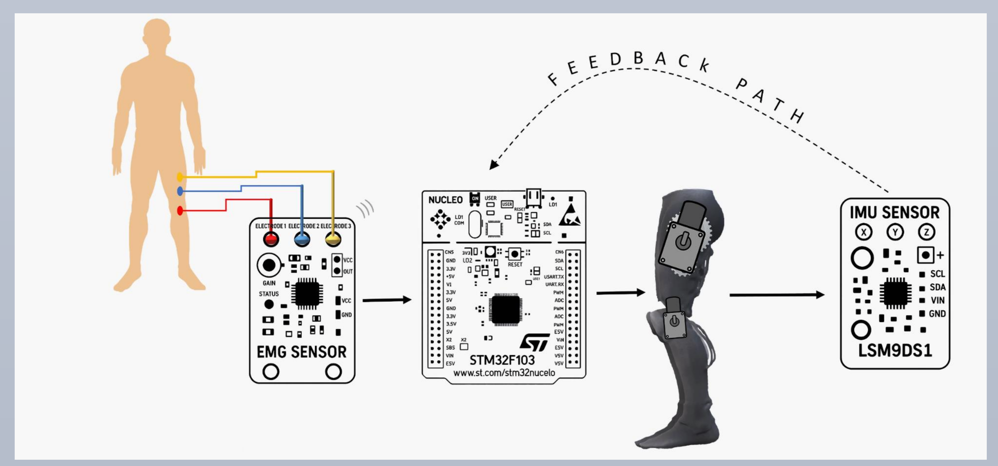

Fig. 4 System Architecture

Mathematical Model

- $V_{out} = G \times V_{muscle}$

The raw muscle signal V_{muscle} is amplified by the EMG sensor to produce an output voltage V_{out}

- $ADC\ Value = \frac{\text{Input Voltage}}{V_{ref}} \times 4095$

Input Voltage: V_{out} from the emg sensor

V_{ref} : Reference Voltage of the 12 bit ADC

4095 is the maximum value for 12 bit ADC

- $Muscle\ Activity\ (\%) = \frac{\text{ADC Value}}{4095} \times 100$

- $Motor\ Torque = A + \left(\frac{\text{Muscle Activity (\%)}}{100}\right) \times (B - A)$

→ A is the min. torque
→ B is the max. torque

- $\text{PWM Duty Cycle} = \left(\frac{\text{Muscle Activity (\%)}}{100}\right) \times \text{PWM}_{max}$

PWM_{max} is the maximum value that the microcontroller's PWM timer can reach, defining the full scale of the PWM signal's duty cycle.

- $\theta_{acc} = tan^{-1}\left(\frac{a_x}{\sqrt{a_y^2+a_z^2}}\right)$

Estimates tilt angle using accelerometer data along the X, Y, and Z axes.

- $\theta_{\text{gyro}}(t) = \theta_{\text{prev}} + \omega_x \cdot \Delta t$

Calculates gyroscope angle by integrating angular velocity over time.

- $\theta_{\text{final}} = \alpha \cdot \theta_{\text{gyro}} + (1-\alpha) \cdot \theta_{\text{acc}} u(t = K_p \cdot e(t) + K_i \cdot \int e(t)\, dt + K_d \cdot \frac{de(t)}{dt}$
- $e(t) = \theta_{\text{desired}} - \theta_{\text{measured}}$

PID controller is implemented

Fig.5: Mathematical model

Results

Fig. 6: Sitting and Standing position angles

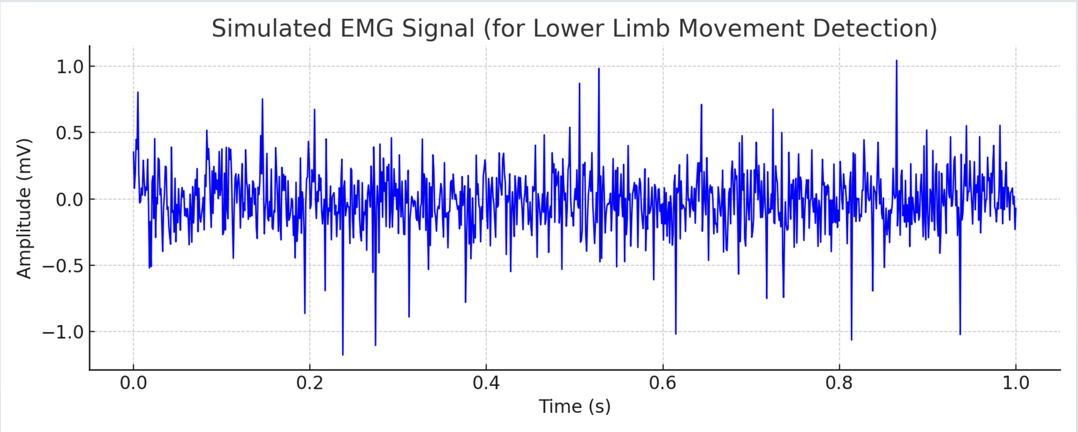

Fig. 7: Signal detection of EMG sensors

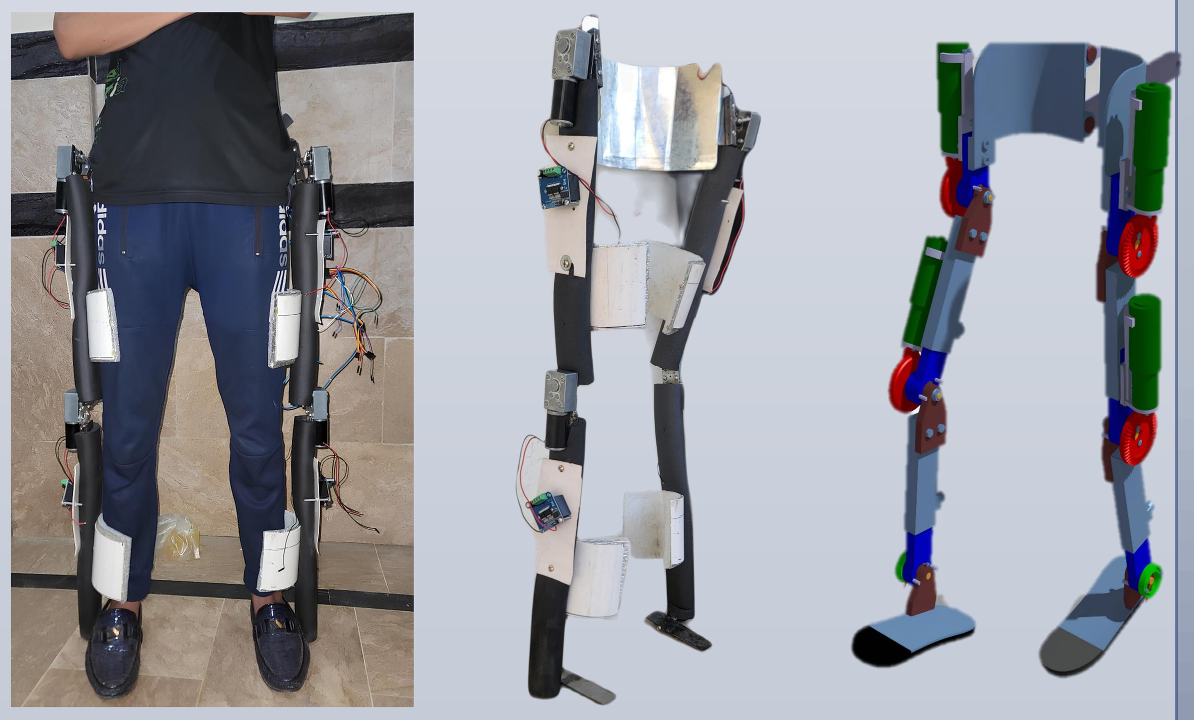

Fig. 8: Wearable Robotic Suite

Conclusion

- The system effectively improves lower limb mobility, enabling independent movement through a microcontroller-based control system that ensures precise, smooth, and adaptive motion tailored to user needs.
- Advanced sensors (EMG, IMU) are seamlessly integrated with the mechanical frame and DC gear motors, delivering a reliable and responsive assistive solution that adapts instantly to user muscle signals for immediate movement assistance.