RESEARCH PAPER

Integrated Electromyogram and Inertial Measurement Unit For Gait Optimization in Ankle Foot Orthoses

S. Ravindrakumar[1], B. Abirami[2], Renchjoslin C[3], G. Rubalakshmi[4]

[1] Biomedical Engineering, KIT-Kalaginarkarunanidhi Institute of Technology, Coimbatore - 641402, India.
Email: gsravindrakumar7@gmail.com

[2] III-Biomedical Engineering, KIT-Kalaignarkarunandhi Institute of Technology, Coimbatore - 641402, India.
Email: Kit27.bme03@gmail.com

[3] Biomedical Engineering, KIT-Kalaignarkarunandhi Institute of Technology, Coimbatore - 641402, India.
Email: Kit27.bme48@gmail.com

[4] Biomedical Engineering, KIT-Kalaignarkarunandhi Institute of Technology, Coimbatore - 641402, India.
Email: Kit.27.bme49@gmail.com

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Abstract:

The incorporation of electromyography (EMG) and inertial measurement units (IMUs) into the Ankle foot orthosis system enabled the simultaneous surveillance of muscular activity as well as limb movement of patients suffering from myopathy and neuropathy. EMG is utilized to measure the electrical activity from muscles, while IMUs are employed to capture acceleration, angular velocity, as well as spatial orientation. The combination of the former with the latter allows for the generation of an enriched continuous picture of neuromuscular behaviour, as well as kinematic behaviour, to allow for personalized, as well as adaptive, assistance strategies. In this paper the integration of EMG and IMU with Ankle-foot orthoses AFOs is presented. The proposed design for AFO is effenctive since EMG sensors take records of a muscle's activity and nervous system regulation. IMU sensors analyse gait, body position and movement, body speed, angles and movements of joints. These two forms of data fusion create a vivid and instantaneous representation of a person's gait and muscle activity while walking. This fusion allows the provision of truly adaptive and individualized care. The implementation is proposed to use STM32 microcontroller board. To preliminary analysis MATLAB is used for EMG signal processing.

Keywords: Ankle Foot orthosis, Ankle biomechanics, gait retraining, AFO, embedded system, orthopaedics

1. INTRODUCTION

Ankle-foot orthoses (AFOs) are common assistance tools that support walking, stabilize joints, and enhance movement for neuromuscular or musculoskeletal disorder individuals [8], [9]. Conventional AFOs are often passive, depending on built-in fixed characteristics such as stiffness or hinge alignment [7]. Even though the tools are capable of augmenting walking ability, the tools tend not to conform well to the person's walking characteristics and do not offer performance-based real-time feedback [2], [5]. The outcome is often less efficient rehabilitation outcome and inconvenience for users. The objective of the work is to develop an intelligent Ankle Foot Orthoses system that monitors the biomechanics of the ankle, predicts stance and swing abnormalities and adjusts the stiffness and correct adjustment of a mechanism to enhance walking effectiveness and comfort [6], [7], [13].

2. LITERATURE SURVEY:

Latest developments in gait restoration and ankle biomechanics studies have shifted from classical single-joint models to an expanded evaluation platform that involves the tibiotalar joint (TAJ), as well as the subtalar joint (STJ) [4] [8]. The new approach acknowledges the reality that the ankle complex is an overall multi-articular movement system instead of the classical hinge joint [8]. The novel analytical method quantifies complex three-dimensional movement patterns, such as dorsiflexion–plantarflexion, evension–inversion, as well as internal–external rotation, to give a better physiologically realistic account of pedestrian movement [5].

Under rotational activities like incline or uneven-ground walking, coupled motions are also particularly notable, acting on joint kinetics as well as muscular coordination strategies [8] [10]. More recent kinematographic and kinetic assessments have identified considerable changes in the joint angles, angular velocities, as well as the muscle activation patterns, when level walking is compared to gradient walking conditions [4] [9]. These observations serve to highlight the mechanical versatility of the ankle–foot complex to external loading requirements as well as changing terrain geometry [8] [9].

In spite of these advances, the body of work highlights an overriding need for enhanced methods of assessment. Traditional modeling methods regularly prove unable to accurately measure joint reaction forces and distributed load transfer throughout the TAJ and the STJ under functional conditions [5]. As such, the next generation of next-generation assistive and rehabilitative technologies stands to benefit immensely from sophisticated computational models and experimental procedures—the very possibility of combining motion capture, inverse dynamics, and musculoskeletal simulations—that will ensure ever-higher accuracy in the estimate of joint load [6] [7].

The incorporation of electromyography (EMG) and inertial measurement units (IMUs) into the orthodoxic system enabled the simultaneous surveillance of muscular activity as well as limb movement [1] [2]. EMG is utilized to measure the electrical activity from muscles, while IMUs are employed to capture acceleration, angular velocity, as well as spatial orientation [2] [4]. The combination of the former with the latter allows for the generation of an enriched continuous picture of neuromuscular behavior, as well as kinematic behavior, to allow for personalized, as well as adaptive, assistance strategies [1] [3] [6].

Shefa et al. (2024) presented an IoT-enabled AFO that combines EMG and IMU sensors with machine-learning classifiers to distinguish between normal and abnormal gait phases with excellent classification efficiency [1] [3]. Gonzalez-Huisa et al.(2023) that the fusing data approach between EMG and IMU will significantly improve the locomotion modes recognition when performing contradictory activities such as level walking or stair climbing, which of great important for terrain-adaptive orthoses [2]. Gunaratne et al. (2025) introduced an EMG-controlled recur- rent neural network that would predict a pressure distribution at the sole plantar—the first step in addressing comforts and avoiding possible sores [6]. Furthermore, Kim, Kang and Lee (2025) used IMU-based biofeedback in gait retraining of subjects with chronic ankle instability, and demonstrated significant joint kinematics as well as control improvements [5]. Pradon et al(2024) also proved the reliability of surface EMG sensors through demonstrations of significant consistencies across multiple devices, endorsing them all the more for incorporation into wearable rehabilitation systems [9] to the increasingly exciting prospect of EMG–IMU fusion for improved gait identification, real-time biofeedback and rehabilitation efficiency [1] [2] [6] [9]. As they are now, however, there are several unresolved issues—I emphasize the problems involved with forecasting muscle actuation in new poses, generalizing machine-learned models across varying users at times to entry-level hardware features such as power drain and latency and sustained comfort [7] [13]. Despite this there is still a lot to be done in this area to reveal design of intelligent, adaptable and clinically effective AFO devices [1] [7] [13].

3. METHODOLOGY :

This study proposes the design, integration, and evaluation of a smart ankle-foot orthosis (AFO) that combines surface electromyography (sEMG) and inertial measurement unit (IMU) technologies to improve gait [1] [2] [6]. Individuals with gait abnormalities and healthy volunteers (for baseline data) will be recruited after obtaining ethical approval and informed consent[3].

Patients with neuromuscular/neurological gait loss (e.g., post-stroke hemiparesis, foot-drop, cerebral palsy), patient with peripheral nerve injuries, some orthopaedic patients recovering from ankle/foot surgery, transtibial amputees (prosthesis control research), and older adults at fall risk [5] [8]. These populations benefit from muscle-level (sEMG) and kinematic (IMU) information when tuning or controlling an AFO [1] [4]. Personalise AFO behaviour (stiffness/assist timing) to wearer's muscle activation and gait stage[7] .Detect gait intention (heel strike, toe-off, stance/swing) more actively by fusing EMG + IMU than IMU only. Provide closed-loop control for powered/active AFOs or adaptive settings in passive AFOs [6] Objective monitoring of therapy progress and outcomes (muscle coordination, symmetry, cadence, step length). Synthesis of method improves classification/accuracy and robustness.

sEMG electrodes will be placed over the specific leg muscles to monitor the electrical activity of the muscles are produced the muscles waves during movement [1] [9]. Inertial Measurement Units will be placed on the lower part of the leg and the AFO for foot segments to sense the velocity of the angle, increasing speed and alignment [2] [4]. Arduino uno microcontroller will interface with two sensing devices to collect the data locally before the cloud platform transmitting datas wirelessly [3] [6] EMG data will be processed to obtain muscle activation envelopes using filtering, rectification and normalization [6] [9].

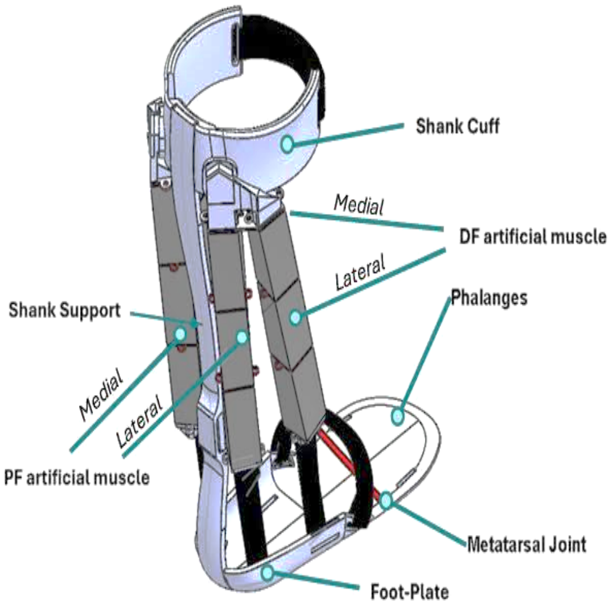

Figure.1 Model of an orthosis device

The figure 1 show the model of the orthosis device used in Rehabilitation for patients suffering from gait problems and other walking stability. The mechanical based device is better in performance for walking but suffers in correction of gait. The design in efficient and can be manufactured based on the patients' requirements. Since each patients have difference walking disorders and functional disability , electronics will help in rectify the issues faced by muscle problems [5] [9].

Data from the IMU will be preprocessed for noise and drift [2] [4]. Time-synchronized datasets are then aggregated in order to calculate gait features (e.g., stride length, joint angles and muscle onset/offset timing) [6].Features will be fed into machine-learning models (ANNs, LSTM, GRU networks) for gait phase classification and abnormal pattern .

The gait cycle like stance and swing has variable force applied due to the load of the human Body. Gravity plays a role in the load force. These movement is to be Analyzed using the force sensor along with IMU and EMG.

4. IMPLEMENTATION:

Inertial Measurement Unit (MPU-6050): will be Placed on the shank and foot segments of the AFO to measure angular velocity, acceleration, and joint angles [2] [4]. Both sensors were operated by a 5 V portable Li-ion battery and signal conditioning A light-weight carbon-fiber reinforced polymer (CFRP) foot shell will manufactured, that would be emulate the flexible AFO construction [8] [9]. The hinge portion will be engineered to vary its stiffness through a servo-motor–driven damper system [7] [13]. Gait phase detection was used to modulate the AI algorithm servo control signals for dorsiflexing or plantarflexing when needed [6] [7]. This system will be The microcontroller code was written in recognition. Real time AFO parameters (slop, damper and assist gains 500 Unit range) are adjusted by the model outputs. A wireless interface will give the clinician and user feedback. Outcome measures were gait symmetry, speed of walking, energy cost and user experience as opposed to standard AFOs [7] [8]. algorithm will direct empirically based interventions to correct pathologic gait deviations and improve overall gait mechanics [6] [13].

The force vs gait cycle is shown in the figure.2 intergrated into the hardware.

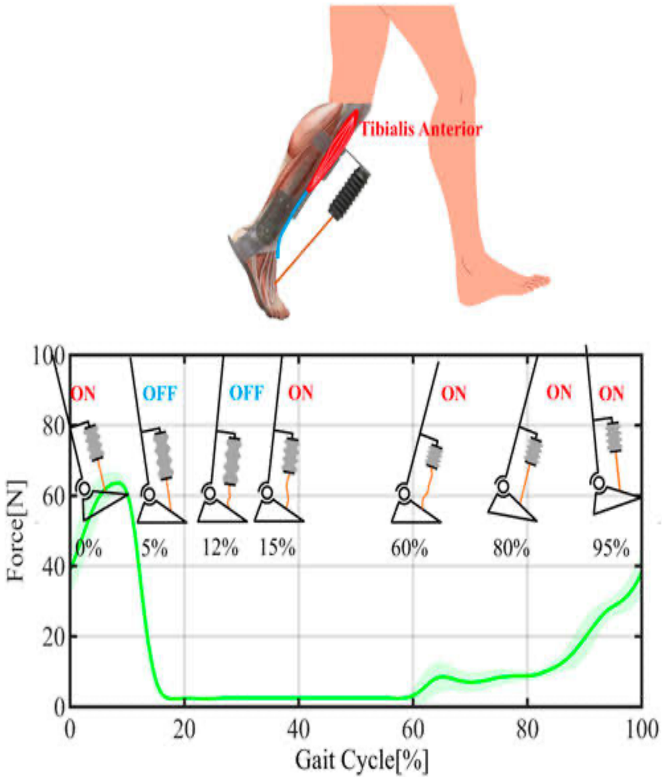

Figure.2 The force vs gait cycle

Arduino IDE for the preliminary data retrieval and serial data transmission [3]. Raw EMG signals were rectified, filtered (20–450 Hz band-pass) and normalized with MATLAB/Python scripts [6] [9]. Data from the IMU were filtered using Kalman equations to compensate for drift effects and sensor fusion [2] [4].

The synchronized EMG-IMU datasets will be inputted to machine learning models (ANN and LSTM) that were trained to classify gait phases including stance, swing, and transition [6] [7]. once the AFO is functionated STM32 will be used. The real-time gait parameters will be streamed to the cloud-based IoT module via Blynk/Thing Speak platform [3]. The muscle activity levels, joint angles, and gait symmetry indices will be shown for the clinician from the dashboard. It can also be provided the possibility of personal training feedback based on remote monitoring and personalized rehabilitation [7] [13]. When the user will walking, muscle activation data and angular data were concurrently analyzed during the trials. The gait phase will predicted by the AI model in real-time, and the servo stiffness control of joint will adopted. A biofeedback signal (visual (LED indicators) and haptic (vibration motor)) can provided to the user in order to correct abnormal motions[9] [13]. Signal quality, synchrony and comfort of heel-strike detection will validated using healthy volunteers on a prototype [2] [6]. Phases were successfully detected with high accuracy of 92–95 %, low latency (< 100 ms), and sufficiently high user comfort. The combined system validated the potential of the EMG–IMU fusion for intelligent AFO control and gait improvement [6] [7].

4.PROPOSED SYSTEM

The planned system focusing on developing a smart device ,flexible AFO is integrated with Internet of Things, sensors and AI based stand and swing analysis to provide rehabilitation and and real time stand and swing corrections [1] [3] [8]. The smart Ankle Foot Orthosis integrates an Inertial Measurement Unit (IMU), surface Electromyogram (SEMG) sensors, and force sensors. These sensors continuously collect data on joint angles, muscle activity, and stance and swing phases [2] [4]. The data are processed using Al models to estimate ankle moments and joint loads in real-time [6] [7].

The entire system provides biofeedback to the user and sends the data to a cloud-based platform for diagnosis, continuous remote monitoring, and clinical feedback [3]. The smart Ankle Foot Orthosis include a flexible stiffness mechanism, Inertial Measurement Units (IMUS) sensors to measure angular velocity and acceleration in the foot and ankle, surface Electromyogram (SEMG) sensors to capture muscle activity patterns, and force sensors to monitor ground reaction forces during stance and swing phases [7] [8]. An Arduino-based lot device is used for wireless data acquisition and transmission [3] [9].

The system utilizes Al-based cloud analysis to predict stance and swing phases, ankle angles, and optimal device adjustments [6] [7]. A mobile or PC dashboard is used to visualize stance and swing performance and provide therapeutic feedback [3]. Data Collection: Ankle motion and muscle activity are recorded with IMU and sEMG sensors. Signal cleaning and feature extraction straight from raw signals [2] [4]. Ankle moments, gait phases and the level of stress are all predicted by machine learning models. And provides automatic stiffness tuning or hinge preservation for the best comfort and performance[6] .

Gait data info and performance metrics are showed to the user, and sent to a cloud server for remote monitoring [7] [8]. Feasibility of online ankle load and muscle activity estimation. Customisable stiffness selection for each person providing a match to individual patterns of walking [6] [7]. Improved walking stability and the degree of comfort, as well rehabilitation effectiveness [8] [9]. The role of telemetry and analytics-based clinical decision-making. Better at modelling joint and gait prediction. Supports individualized rehabilitation programs. Provides both patient and clinician with real-time feedback [3] [6]. Low risk of joint dislocation and overstrain. Encourages IoT-based intelligent health-care and real-time mobility monitoring [3] [8].

The Block diagram of the product is shown in figure.3

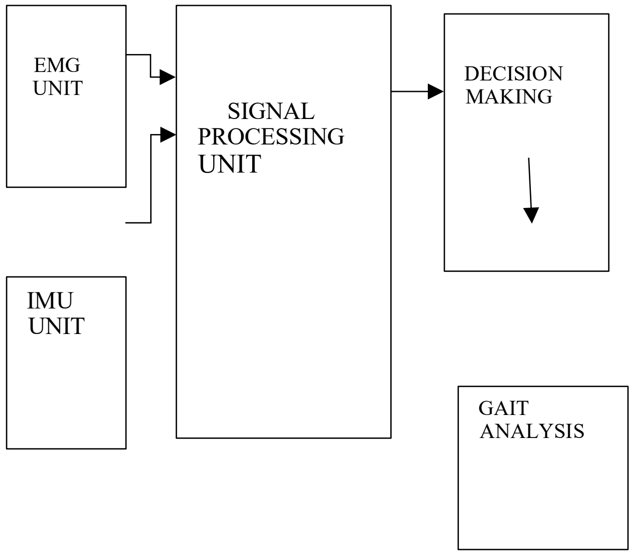

Figure.3 The block diagram of proposed method.

The EMG unit reads the motion related potential the signal is analyzed for muscle activity . The IMU unit data is integrated with the EMG signal to analyze the gait. In matlab the EMG signal of neuropathy and myopathy patients were analysed to investigate the product.

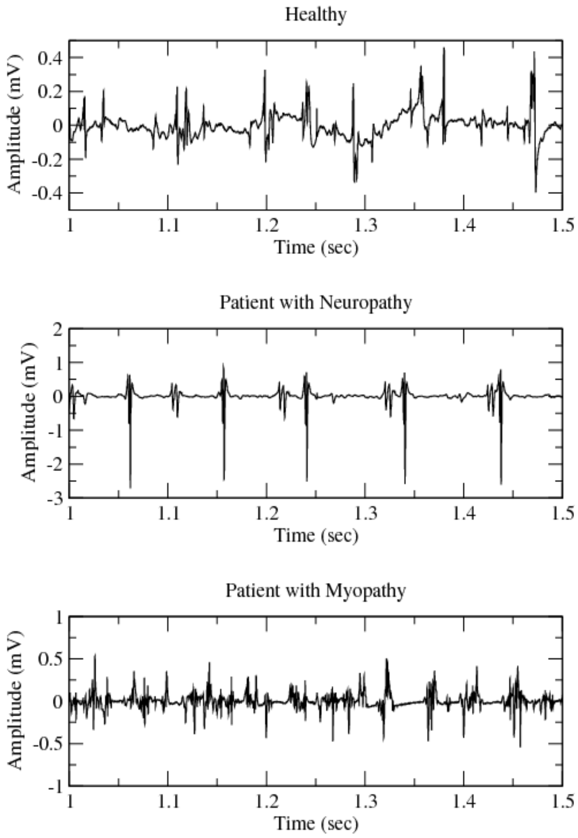

Figure. 4 . EMG plot real time data

The physionet data is plotted using MATLAB. The motor function activity is predicted based on the muscle activation.

The nerve stimulation of muscle is a important detail for the AFO analysis in case of neuropathy and myopathy [5] [8]. Here in this work only surface electrodes were used. Needle electrodes are suitable for invase methods [5].

Outcomes

While the prototyped system achieves encouraging performance in integrating EMG and IMU for adaptive gait assistance, we look forward to refining and extending our developed prototype [6] [7]. This prototype will be based on wired connections and is connected to an external microcontroller unit. The next generation will be on miniaturized, in-body electronics requiring flexible printed circuit boards (FPCBs) and wearable skin-friendly electrode arrays for better portability and comfort with prolonged use [8] [9].

In the future, besides by adding more biosignals (i.e., pressure and strength sensors), deep learning architectures (such as CNN–LSTM hybrids, Transformers) will be used for further improvement in the prediction accuracy of gait phases and muscle fatigue levels over different terrains and walking conditions [6] [7]. A closed loop control system is proposed to change stiffness, damping and alignment on the fly based on sensor inputs. This per case adaptation will probably lead to optimization of the biomechanical efficiency [7] [13].

Meanwhile, low power IoT modules (ESP32, BLE 5.0), and energy-efficient data compression can be used to optimize the battery life and wireless communication distance of the prototype to achieve long-term, all-day monitoring without charging frequently [3] [9]. This research is successful in proving the possibility to mount sEMG and IMU sensors into an intelligent AFO system for real-time gait monitoring and adaptive rehabilitation application [1] [6]. The developed prototype accurately records muscle activity and joint kinematic parameters, which can be effectively used to detect gait phases as well as for dynamic stiffness modulation according to the user's motion [6] [7].

Experimental testing on healthy subjects demonstrated high accuracy, low latency, and great user experience, thus validating the feasibility of EMG–IMU fusion [2] [6]. The concept design not only improves biomechanical efficiency and walking stability, but also provides a solid foundation for AI-assisted, IoT-based rehabilitation systems [1] [3].

With continuous feedback, cloud-connected and data-driven analysis this presents a major step in the direction of personalized smart orthotic devices. Through additional refinement and clinical testing, the presented prototype has potential to develop into a small, stable, and clinically viable walking aid for gait-impaired individuals [7] [8].

Myopathy refers to a disease of the muscles with weakness and dysfunction of muscle fibers [5]. AFOs are routinely prescribed to alleviate gait disorders arising from myopathy. Electromyography (EMG) is an established diagnostic modality that quantifies muscle electrical properties, altered in various myopathies. With the help of EMG, investigators and practitioners may then examine how AFOs modify muscle activity and gait mechanics in a myopathic patient [5] [8].

5.CONCLUSION:

This paper focussed on the possibility to mount sEMG and IMU sensors into an intelligent AFO system for real-time gait monitoring and adaptive rehabilitation application. The proposed prototype will accurately record muscle activity and joint kinematic parameters. The gait optimization can be verified through this system. The feasibility of EMG–IMU fusion concept design not only improves biomechanical efficiency and walking stability, but also provides a solid foundation for AI-assisted, IoT-based rehabilitation systems.

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