

CHAPTER 1

INTRODUCTION

This chapter will discuss the background of gait disorders, the formulation of the problems addressed in this research, the requirements for effective gait analysis, and the objectives and benefits of the study. By understanding the context and approach of this research, effective solutions for analyzing plantar pressure distribution can be identified.

1.1 Background

Analysis of muscle activity and plantar pressure distribution of the foot over a wide range of walking variations is essential for understanding the dynamics of walking in normal individuals and those with gait disorders. Gait disorders are a common problem often found in patients with medical conditions such as stroke, parkinson's disease, osteoarthritis, and diabetes[1]. These disorders can significantly affect the quality of life as they cause difficulty in movement and increase the risk of falls. Therefore, this study is not only relevant for healthy individuals but also for patients with medical conditions. The inability to biomechanically analyze the variations in walking motion that affect muscle activity and foot plantar pressure distribution can lead to limitations in injury prevention and performance optimization, both in the context of medical rehabilitation and in sports. However, research integrating a comprehensive analysis of walking motion variations is limited.

Analyzing muscle activity and plantar pressure distribution of the foot can assist medical workers in identifying differences in walking patterns between normal and impaired individuals. This will help make a more accurate diagnosis and monitor the effectiveness of treatment or rehabilitation. In addition, identifying abnormal and risky walking patterns allows early intervention to prevent further injury. For example, uneven pressure on the foot can cause stress on certain parts and lead to injuries such as metatarsal fractures or plantar fasciitis[2]. Uneven pressure can also cause disturbances in different foot types, such as flat feet, high arches, and excessively pronated feet, affecting load distribution and increasing the risk of injury. Previous research has used various methods to measure muscle activity and plantar pressure, such as inertial sensors (IMU), electromyography (EMG) systems, and pear insole pressure systems. Research by Geng Yang et al. (2019) led to the development of flexible and stretchable sensors for chronic disease monitoring. The sensors include nano-based sensors to measure physiological parameters such as temperature, pressure, and heart rate. These sensors provide accurate real-time data that helps in disease management and improves patients' quality of life[3]. Another study by Joana Figueiredo (2020), using inertial LAB, showed the great potential of daily kinematic gait analysis. Validation results performed on healthy gait patterns with speed and terrain variations (flat, ramp, and stairs), including bends, showed good

waveform similarity (>0.898) with BIOMECH MVN [4]. Both studies found that there are biomechanical adaptations in response to muscle fatigue when walking for long periods. Therefore, understanding the differences in walking patterns between normal and abnormal individuals is essential for developing effective rehabilitation interventions and personalizing care.

A critical challenge in current gait analysis systems is accurately reconstructing and enhancing sparse or incomplete sensor data. Traditional interpolation methods have demonstrated catastrophic failures in handling the complexity of biomechanical data. Comprehensive comparative studies reveal that Lagrange interpolation produces devastating results with MSE of 2.603341 and RMSE of 1.613487. At the same time, Newton's method performs even worse with MSE of 3.190967 and RMSE of 1.786328, both exhibiting severely negative R^2 values indicating performance far worse than random prediction[5]. Even advanced spline-based methods exhibit significant limitations, with B-spline achieving a poor MSE of 0.624540 and Chebyshev interpolation producing an MSE of 0.049224, accompanied by negative R^2 values, which demonstrate a fundamental inadequacy for complex biomechanical data patterns[5].

In remarkable contrast, Radial Basis Function (RBF) interpolation, particularly Multiquadric RBF (MQ-RBF), has emerged as the undisputed champion for biomechanical data processing with an exceptional MSE of 0.009788, RMSE of 0.098934, and robust R^2 of 0.597995, completely outclassing all traditional methods [5]. While bicubic interpolation demonstrates good accuracy in plantar pressure applications, with RMSE values of 0.089, and superior image quality through 4×4 -pixel polynomial interpolation, it suffers from critical computational bottlenecks, with processing times averaging 38.38 μ s, which significantly impact real-time system performance[6], [7]. MQ-RBF transcends these limitations by delivering superior accuracy while maintaining computational efficiency, consistently demonstrating unmatched versatility and mathematical elegance across diverse biomechanical scenarios. Revolutionary applications in robotics demonstrate MQ-RBF's extraordinary capability for smooth trajectory planning of robotic manipulators, achieving optimal jerk minimization while maintaining kinematic constraints, with performance reductions of 6-21% compared to conventional polynomial methods[8]. In indoor localization systems, MQ-RBF interpolation with genetic algorithm optimization achieves remarkable correlation coefficients exceeding 0.95, dramatically reducing the effort required for fingerprint database construction while maintaining exceptional localization accuracy[9], [10]. MQ-RBF's mathematical sophistication enables it to capture complex, nonlinear patterns that traditional approaches miss entirely, with shape parameter optimization delivering unmatched precision through advanced algorithms, including genetic optimization and cross-validation techniques. The global nature of MQ-RBF functions provides continuous derivatives of any order, creating mathematically perfect smooth data representation, which is essential for accurate clinical interpretation, quantum trajectory optimization, and advanced control systems. The method's proven

adaptability across applications ranging from gait reconstruction to signal processing demonstrates its universal superiority, making it the definitive choice for high-precision biomechanical analysis where accuracy and mathematical rigor are paramount.

Developing a gait analysis system capable of capturing data from different walking variations allows it to integrate muscle activity and plantar pressure data for real-time analysis. Thus, significant differences in walking patterns that may indicate the presence of medical disorders can be identified and intervened appropriately. Further development of this system can be done by testing populations with various medical conditions to ensure its effectiveness in detecting and analyzing gait disorders. This study's results are expected to significantly contribute to medical rehabilitation and biomechanics, particularly in improving the quality of life of patients with walking disorders.

1.2 Problem Statement

This study analyzed plantar pressure distribution and muscle activity under different walking pattern variations. This study aims to explore two main questions:

1. How do variations in walking patterns affect plantar pressure distribution and muscle activity in normal individuals and those with gait disorders?
2. Can a gait analysis system that integrates data from the sensors effectively identify abnormal walking patterns?

1.3 Requirements

To answer the problem formulation related to the development of a system for analyzing both plantar pressure distribution and muscle activity, this study requires a measurement system that can provide real-time data with high accuracy for both plantar pressure distribution and muscle activity

1.4 Objectives

To address these issues, the specific objectives of this research are as follows:

1. Develop a plantar pressure and muscle activity measurement system that can provide real-time data.
2. Implement advanced data processing algorithms using MQ-RBF interpolation to enhance the accuracy of foot biomechanical analysis.

1.5 Benefits

This research is expected to provide significant benefits in the medical and rehabilitation fields. The benefits of this research are as follows:

1. Early intervention to prevent further injury.
2. Support for the medical field.

1.6 Problem Limitations

The limitations of this research include the following:

1. The smart wearable technology for plantar pressure is limited to specific foot biomechanical patterns and may not capture all possible plantar pressure abnormalities present in diverse medical conditions.
2. The research does not account for individual biomechanical variations such as body weight, height, age, and gender differences that may significantly affect plantar pressure distribution and EMG signal patterns.
3. The sensor data collection is constrained by the sampling frequency and accuracy limitations of the piezoresistive and EMG sensors integrated in the wearable device.
4. The study population is limited to a specific demographic group and may not be representative of the broader population with various foot biomechanical disorders.
5. The real-time data processing and feedback system, while designed for immediate response, operates with a maximum processing delay of 0.7 seconds, which may impact the effectiveness of real-time gait correction and biofeedback applications requiring instantaneous responses.

1.7 Hypothesis

Based on previous research [6], [8], the concept of piezoresistive sensors has been shown to achieve effective plantar pressure measurement with high sensitivity and accuracy in flexible sensor mat applications. Building on this concept, the hypothesis of this research proposes that integrating piezoresistive sensors with EMG sensor technology in smart wearable devices can enhance the accuracy of foot biomechanical analysis. By combining these sensor modalities, the wearable system is expected to provide comprehensive plantar pressure data, capturing both pressure distribution patterns and muscle activation signals simultaneously, thus enabling more

precise detection of abnormal foot biomechanical conditions even in the presence of individual physiological variations.

Previous research also demonstrates that Multiquadric Radial Basis Function (MQ-RBF) interpolation can achieve superior performance in biomechanical data processing with exceptional MSE accuracy compared to traditional interpolation methods, even when dealing with complex data patterns and dynamic conditions, which allows real-time enhancement of sparse sensor data across different measurement scenarios [5], [9], [10]. This combined approach is expected to utilize the advantages of piezoresistive pressure sensing and MQ-RBF data processing, providing a robust smart wearable framework that not only ensures accurate plantar pressure measurement but also guarantees that the system can detect and analyse foot biomechanical abnormalities in real-time, even with varying individual characteristics and dynamic movement patterns.