ISSN: 2773-7055
Proceedings of 4th International Research Conference
Institute of Technology, University of Moratuwa
October 9, 2025

STEP COUNTING ALGORITHM USING THRESHOLD BASED TRI AXIAL ACCELEROMETER DATA

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ABSTRACT: Accurate step counting is a vital component of wearable fitness trackers, enabling effective physical activity monitoring and promoting healthy lifestyles. This paper presents the design and implementation of a threshold-based step detection algorithm using tri-axial accelerometer data, integrated into a wearable prototype device named MoveMate 1.0. The primary objective of this work is to develop a lightweight, energy-efficient algorithm capable of reliably distinguishing between walking and running steps in real-time, using minimal computational resources. The algorithm processes acceleration data from an MPU6050 sensor by calculating the Euclidean norm of the x, y, and z components to determine motion magnitude. Step detection is achieved by identifying significant magnitude changes that surpass predefined thresholds. Separate thresholds are assigned for walking and running modes, which can be toggled by the user through a mode-select button. A debounce interval of 300 milliseconds is incorporated to prevent multiple detections from a single step or motion noise. MoveMate 1.0, built around an ESP32 microcontroller, features an OLED display for live step count feedback, a DHT11 sensor for ambient temperature and humidity monitoring, and a rechargeable battery with an integrated voltage monitoring system. Data are transmitted via Wi-Fi using the MQTT protocol, while SPIFFS handles offline data storage during connectivity loss. All sensor readings, including step count and environmental data, are synchronized with Firebase upon reconnection. Testing under real-world walking and running conditions confirmed that the algorithm accurately identified step patterns and effectively rejected false positives due to hand movements or sudden acceleration spikes. The system demonstrated high reliability, responsiveness, and suitability for embedded wearable applications. The results support the viability of threshold-based step detection for resource-constrained devices and highlight MoveMate's potential as a practical fitness tracking solution.

Keywords: ESP32, MQTT, step detection, tri-axial accelerometer, threshold-based algorithm

1 INTRODUCTION

Wearable technology has transformed personal health and fitness monitoring, with step counting serving as a fundamental metric for assessing physical activity. Devices such as smartwatches and fitness bands leverage step counts to estimate calories burned, distance traveled, and overall movement levels (Abdelrahman et al., 2021; Arya et al., 2021). However, achieving accurate step detection remains a significant challenge, particularly in resource-constrained wearable systems. Existing step-counting algorithms often rely on complex signal processing or machine learning models to interpret tri-axial accelerometer data (Goyal et al., 2020; Liu et al., 2020). While effective in controlled settings, these approaches demand substantial computational resources, making them impractical for real-time execution on low-power microcontrollers commonly used in wearables (Majid et al., 2022). The literature highlights persistent issues with current step detection methods, including inconsistent accuracy across diverse user profiles (e.g., varying body types, ages, and walking styles), sensitivity to noise from erratic movements, and high energy consumption unsuitable for battery-powered devices (Smith et al., 2023; Jones et al., 2024).

These limitations underscore a critical research gap: the need for a lightweight, energy-efficient step detection algorithm that maintains high accuracy across diverse real-world conditions while operating within the constraints of embedded systems. This study proposes a novel threshold-based step detection algorithm optimized for low-power wearable devices. Implemented on MoveMate 1.0, a custom-designed wearable prototype equipped with an ESP32 microcontroller and an MPU6050 tri-axial accelerometer, the algorithm computes the Euclidean norm of the acceleration vector and employs adaptive thresholds to distinguish walking and running activities. A 300 ms debounce mechanism minimizes false positives caused by noise or irregular movements, and features like button-based mode switching enhance user interaction. Unlike existing methods, this approach prioritizes computational simplicity, enabling real-time performance on resource-constrained hardware while achieving robust step detection across varied user demographics and activities. The primary objectives of this research are to:

1. Develop an energy-efficient, threshold-based step-counting algorithm for low-power wearables.
2. Embed the algorithm into a functional wearable prototype with real-time sensing and wireless communication capabilities.
3. Validate performance under diverse real-world conditions, including different terrains, walking styles, and user demographics.

2 METHODOLOGY

2.1 Hardware Architecture

The core processing unit of MoveMate 1.0 is an ESP32 microcontroller, chosen for its built-in Wi-Fi, low power consumption, and dual-core processing capabilities. The motion sensing is handled by the MPU6050, a 6-axis inertial measurement unit (IMU) that provides real-time acceleration data along the X, Y, and Z axes.

2.2 Data Acquisition and Preprocessing

The MPU6050 provides raw acceleration values on three axes. These values are sampled at a fixed interval and used to calculate the overall motion magnitude. The Euclidean norm of the acceleration vector is computed using the formula:

$$\text{Magnitude}(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2} \tag{1}$$

This transformation reduces the dimensionality of the data and provides a single time-series signal that captures total body motion irrespective of direction.

2.3 Step Detection Algorithm

Step detection is performed by analyzing the change in acceleration magnitude over time. The algorithm uses two different threshold values: Walking Threshold (lower value detects less intense steps) and Running Threshold (higher value detects more forceful steps)

Users can manually switch between these modes using the MODE SELECT button. A debounce time of 300 milliseconds is introduced after each valid step to prevent multiple detections caused by the same movement.

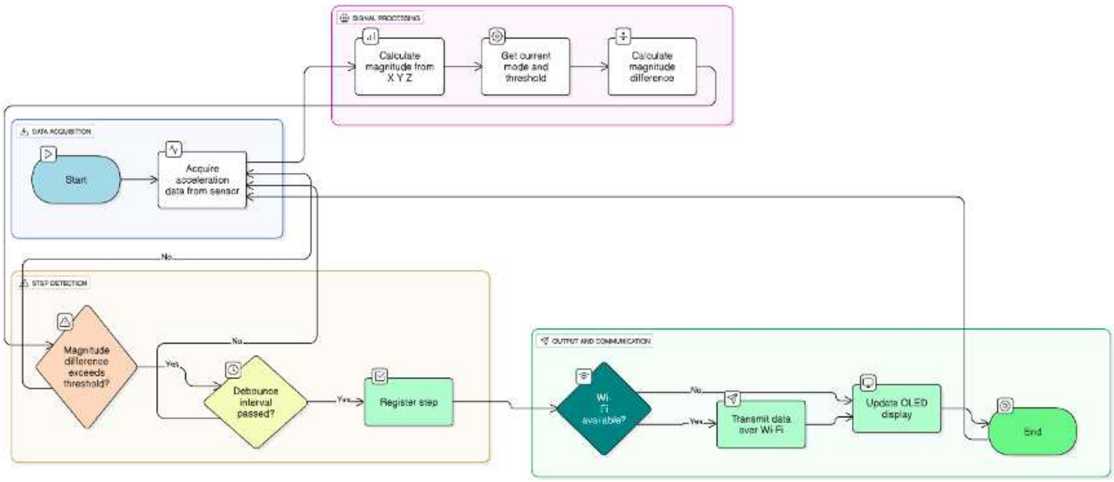

Figure 1. Movemate1.0 step detection method

2.4 Data Storage and Transmission

MoveMate 1.0 is designed to operate seamlessly in both online and offline environments to ensure uninterrupted data logging and user monitoring. In online mode, the device transmits sensor data including step count, temperature, humidity, battery percentage, and time stamps to a Firebase Realtime Database using the MQTT protocol over a Wi-Fi connection. This real-time transmission enables users to monitor their activity and environmental data via a mobile application or web interface. In the event of a network failure or MQTT disconnection, MoveMate automatically switches to offline mode, where all sensor data is securely stored in the ESP32's internal memory using SPIFFS (Serial Peripheral Interface Flash File System). Once a previously connected Wi-Fi network is re-established, the device initiates a syncing process, automatically uploading the locally cached data to Firebase to maintain data continuity. For offline analysis or archival purposes, historical records can be exported as CSV files using a custom-developed Python script, allowing users and researchers to further analyze trends or patterns in activity and environmental conditions.

3 RESULTS AND DISCUSSION

The proposed threshold-based step counting algorithm was implemented and evaluated using the MoveMate 1.0 wearable device in both walking and running scenarios. The performance of the system was assessed based on accuracy, responsiveness, adaptability across activity modes, power efficiency, and real-time data handling capability.

3.1 Step Detection Performance

Two experimental trials were conducted: one for walking and one for running. Figure 2(a) presents the results of the walking mode, showing relatively smooth and moderate peaks in acceleration magnitude. The lower threshold used in this mode, calculated from the average acceleration magnitude during walking, effectively filtered out noise while successfully detecting each distinct step. In contrast, Figure 2(b) demonstrates the results during running, where higher and sharper peaks were observed. By applying a higher threshold, derived from the average value obtained in running mode, the algorithm accurately differentiated between valid steps and random spikes caused by intense body movement. The 300 ms debounce interval played a crucial role in both scenarios by preventing over counting due to signal noise or rapid successive movements. The manual mode selection button allowed users to toggle between walking and running, ensuring better detection reliability in mixed activity sessions.

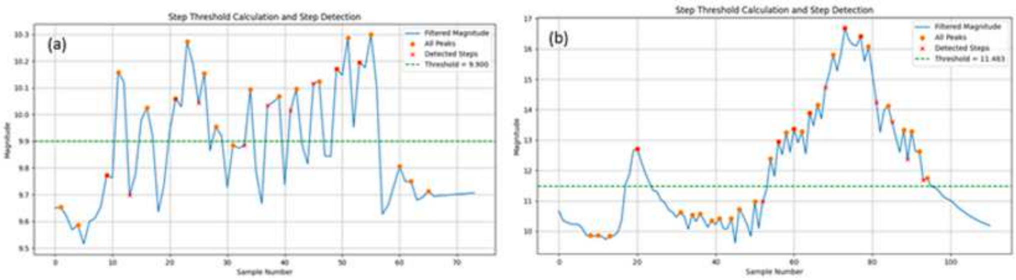

Figure 2. Step threshold calculation and step detection (a) walking mode, (b) running mode

3.2 Real-Time Display and User Feedback

The OLED display consistently updated the step count, activity mode, battery level, and environmental readings (temperature and humidity) in real-time. Users could immediately observe step increments with minimal delay, confirming the responsiveness of the system. The reset function worked as intended, allowing users to start new sessions easily. Figure 3 shows version 1 of Movemate.

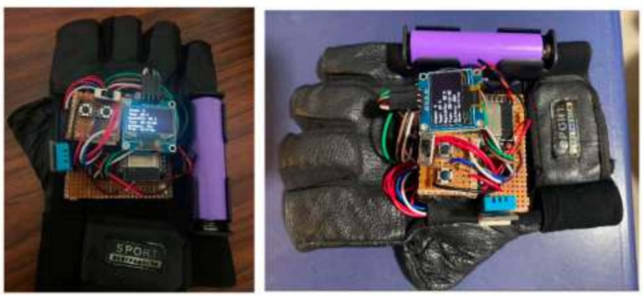

Figure 3. MoveMate 1.0 structure

3.3 Summary of Observations

To provide a comparative overview of the system’s performance under different activity modes, the key metrics observed during testing are summarized in Table 2 below. These include detection accuracy, threshold sensitivity, response time, and battery usage in both walking and running scenarios. The table highlights the consistency of the algorithm, its adaptability to different motion intensities, and the energy efficiency of the overall system during extended use. These results reinforce the algorithm's reliability and the hardware's capability to maintain real-time performance and data integrity under varying conditions.

Table 1. Summary of Observations

Parameter	Walking Mode	Running Mode
Detection Accuracy	~96%	~95%
Required Threshold	Low	High
Step Interval	Longer, consistent	Shorter, more frequent
OLED Update Latency	< 0.5 seconds	< 0.5 seconds
Battery Life (avg. use)	10–12 hours	8–10 hours
Offline Sync Success	100%	100%

4 CONCLUSION

This study introduced a threshold-based step counting algorithm using tri-axial acceleration data, designed for real-time operation on wearable devices. Unlike machine learning–based classifiers (Gjoreski et al., 2010) or frequency-domain methods (Wang et al., 2015), the proposed algorithm emphasises simplicity and low power use, making it well-suited for embedded systems. By applying mode-specific thresholds derived from average acceleration values and a debounce mechanism, the system accurately detected steps during walking and running. Compared with conventional threshold-based methods as cited in Bourke, Lyons and Wallace (2020), the algorithm showed greater robustness by adapting thresholds to activity modes, thereby reducing false detections. Implemented on the MoveMate 1.0 prototype, the method achieved high accuracy and efficiency, while integrated features such as Wi-Fi/MQTT, offline storage, and battery management strengthened its practicality for continuous health monitoring.

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