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IoT-Enabled Wearable System for Real-Time Fall Detection and Elderly Monitoring

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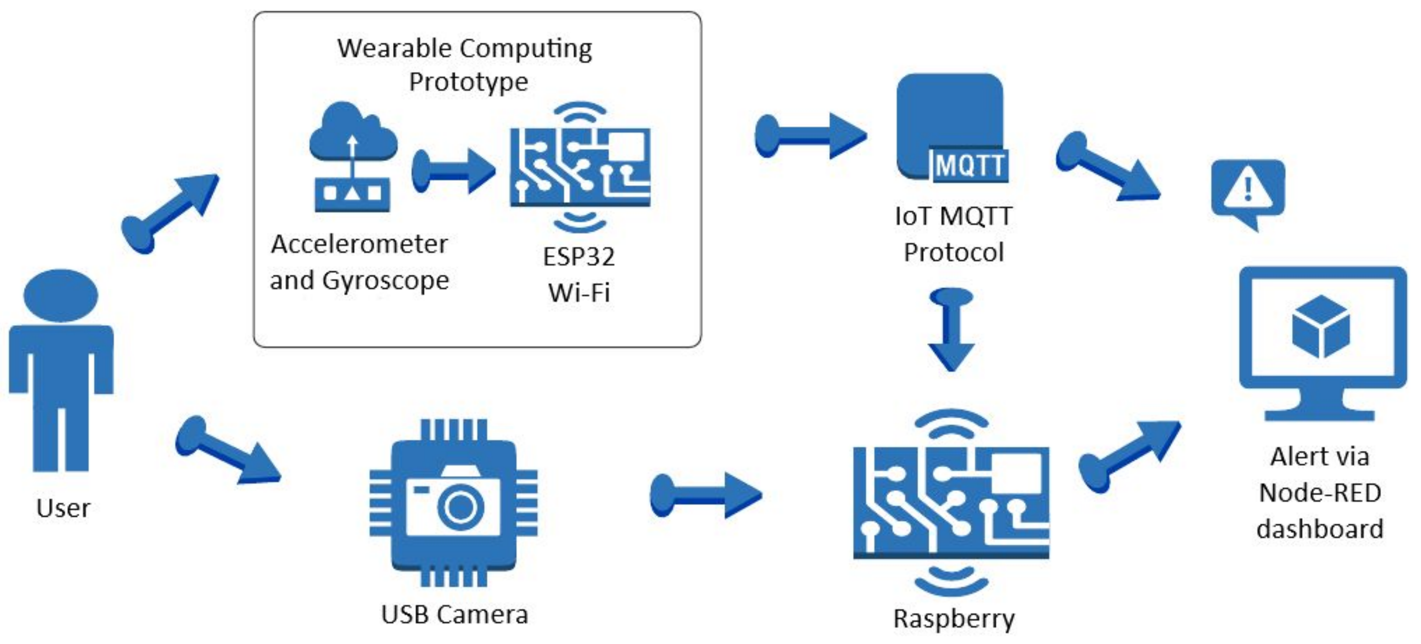
INTRODUCTION & AIM

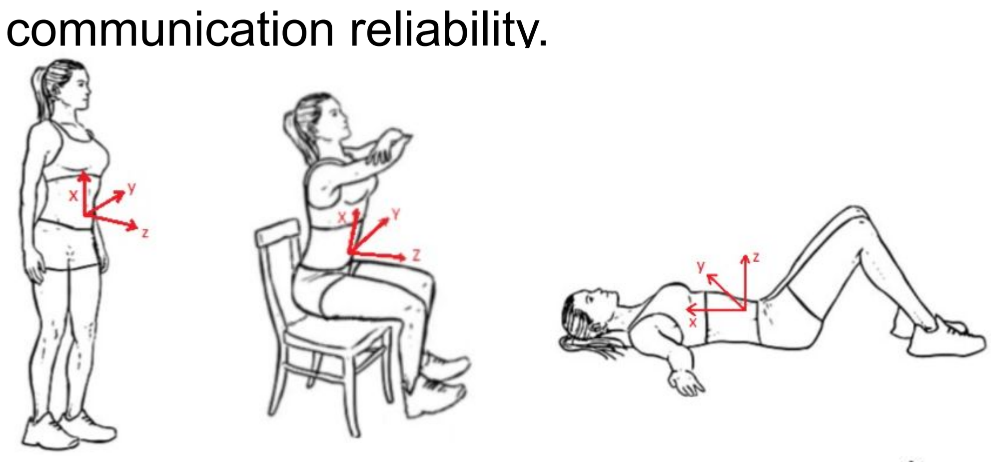
Population ageing and epidemiological data from national and international agencies indicate that falls are among the leading causes of injury and death in older adults, which highlights the need for reliable, real-time monitoring technologies. Camera-based solutions are limited by privacy concerns and restricted coverage, whereas wearable inertial sensors allow continuous monitoring in different environments. However, falls are rare events compared with daily activities, which complicates automatic detection and challenges purely threshold-based methods, particularly for soft falls and complex posture transitions. In this context, this work proposes the design and experimental evaluation of a low-cost wearable system based on an ESP32 microcontroller and an MPU6050 inertial sensor, integrated via MQTT with a Raspberry Pi and a Node-RED dashboard for real-time fall detection and mobility monitoring in older adults.

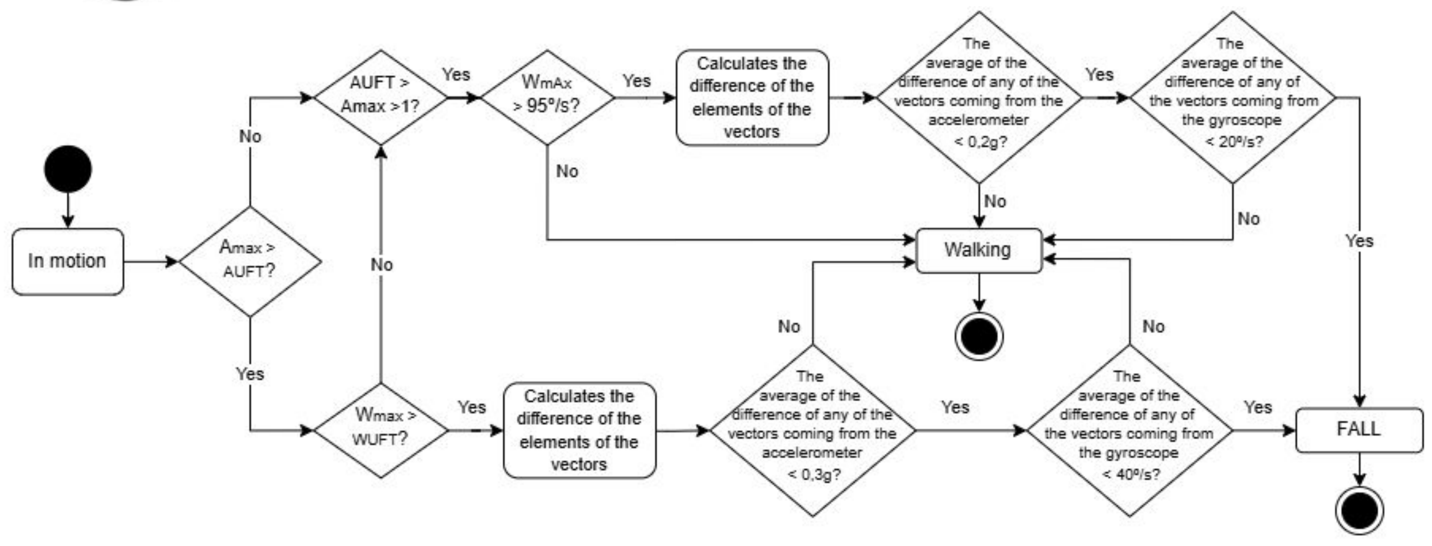


METHOD

The system is structured into data acquisition, processing and visualization layers. In the acquisition layer, an ESP32 and an MPU6050 inertial measurement unit, positioned in a waist pouch, continuously collect linear acceleration and angular velocity along three axes, following the posture-oriented reference frame. The ESP32 encapsulates sensor readings into JSON messages and transmits them over Wi-Fi using the MQTT protocol to a Raspberry Pi 3 edge device. The hardware interface between the ESP32 and the IMU is implemented via I²C, with the corresponding schematic used to design a dedicated PCB that hosts the sensor and a pluggable ESP32 module.

On the Raspberry Pi, Python scripts subscribe to the relevant MQTT topics, parse incoming messages and execute a threshold-based fall detection algorithm. The algorithm computes the magnitude of acceleration and angular velocity and, according to reference thresholds, distinguishes between rest and movement, estimates posture and attempts to classify events as walking or fall. When a potential fall is detected, a camera connected to the Raspberry Pi is triggered to capture an image of the event. A Node-RED dashboard displays in real time the inertial signals, the inferred posture and the images associated with detected falls. Controlled trials comprising walking, standing, sitting, lying and simulated falls were carried out, each repeated three times, and the system output was compared with visual ground truth to assess accuracy and communication reliability.

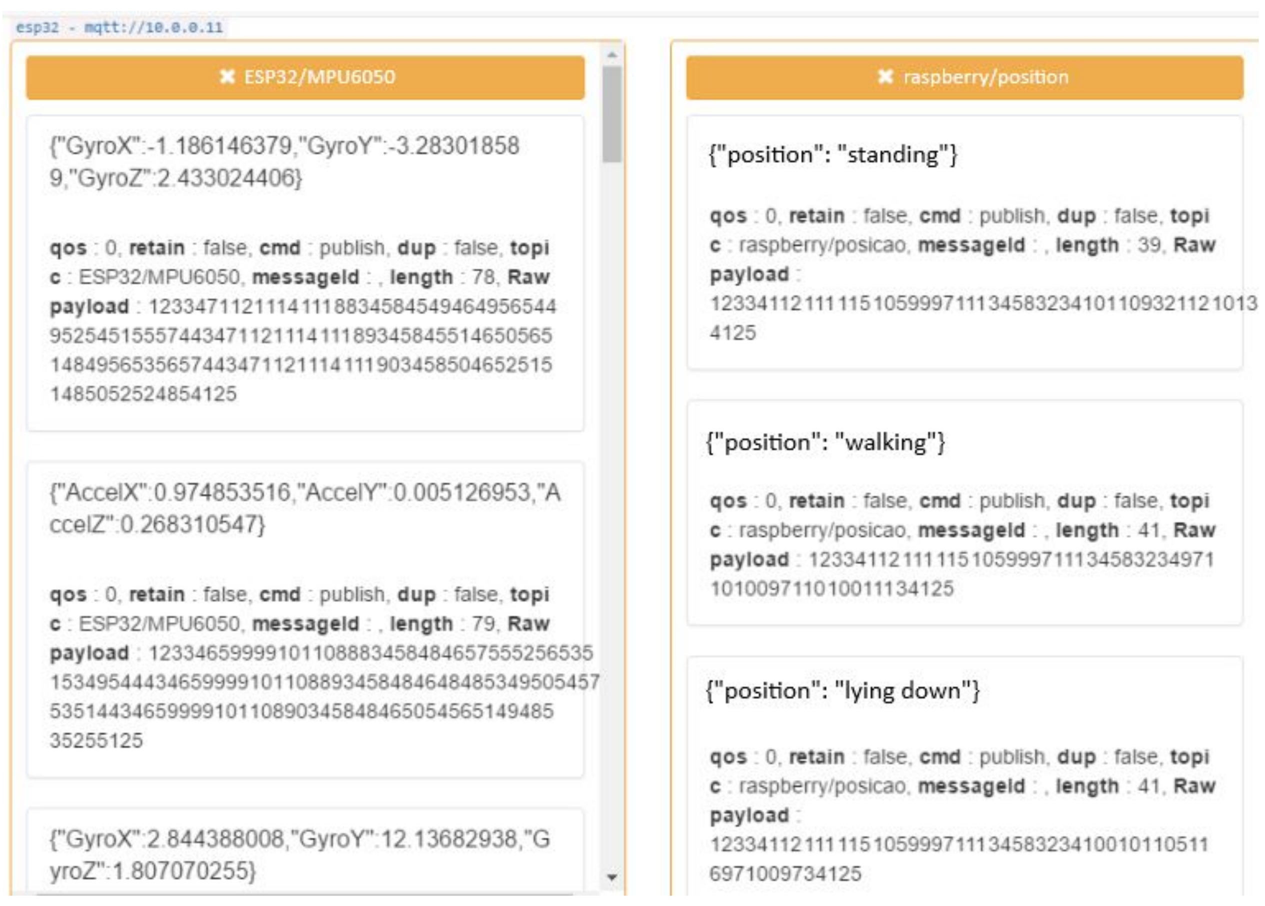


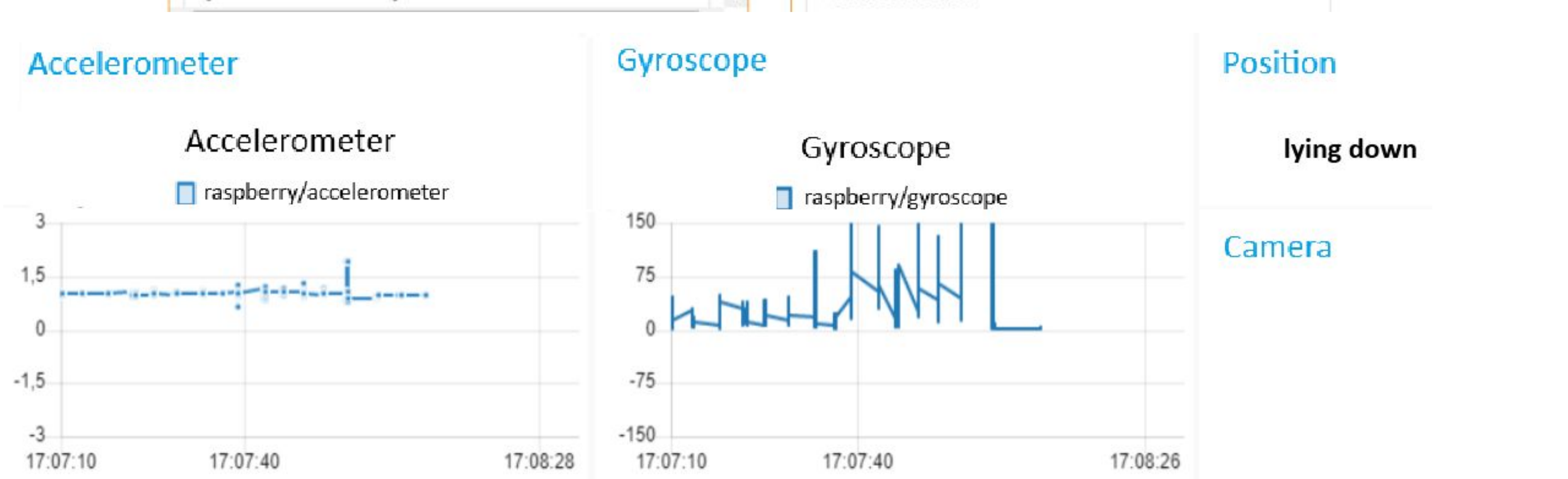


RESULTS & DISCUSSION

Initial tests revealed instability when the ESP32 was powered solely by a 18650 lithium battery, despite nominal compatibility. To ensure stable operation, the subsequent experiments were conducted with the ESP32 powered through a three-metre USB cable, which preserved the intended use at the waist while guaranteeing reliable data acquisition and transmission. Serial monitoring in the Arduino IDE confirmed correct sensor calibration, continuous data acquisition and proper MQTT publication, while MQTTBox verified message reception at the “ESP/MPU6050” and “raspberry/position” topics. The Node-RED interface successfully presented real-time plots of acceleration, angular velocity and inferred posture, and displayed camera images only after fall detections, in accordance with the system design.

In walking trials, the maximum acceleration reached 1.62 g, close to the adopted 1.6 g threshold, and the maximum angular velocity was 396.42°/s, above the 220°/s reference, demonstrating the system’s ability to capture highly dynamic movements. The proposed algorithm consistently classified standing, lying and walking, but failed to correctly identify sitting and the simulated fall events, leading to an overall accuracy of 60% under the evaluated conditions. The mild and severe fall experiments produced clear high-amplitude peaks followed by low-activity intervals in the acceleration and angular velocity signals, which are characteristic of fall dynamics, yet the fixed thresholds were not sufficient to map these patterns reliably to the fall class. These findings confirm the feasibility of the hardware, communication and visualization architecture, while evidencing the limitations of a purely threshold-based approach for robust fall detection in realistic scenarios.





CONCLUSION

This work presented a wearable IoT-based system for fall detection and mobility monitoring in older adults, combining an ESP32 and an MPU6050 inertial sensor in a waist-worn node, a Raspberry Pi 3 edge device and a Node-RED dashboard for real-time visualization. The prototype demonstrated stable wireless communication, correct acquisition and transmission of inertial data, and successful integration of sensor readings, camera images and posture estimates into a single monitoring interface. However, the threshold-based algorithm achieved only 60% accuracy and exhibited specific difficulties in distinguishing sitting from falls and in reliably detecting soft falls, indicating that fixed thresholds alone are insufficient to handle the variability and subtlety of real movements. Even so, the system constitutes a low-cost, modular and non-invasive platform with potential application in home and clinical environments for supporting safer and more autonomous ageing.