WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Smart Prosthetic Leg with Wrist-Worn Fall Alert and Automatic Emergency E-mail Using ESP32

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ABSTRACT:

A person who walks with an artificial lower limb is more likely to stumble, yet an ordinary prosthesis has no way of noticing a fall or asking anyone for help. We built a working prototype that closes this gap at modest cost. An MPU6050 motion sensor fixed to the prosthetic shank is read by an ESP32; the controller raises a fall suspicion when the measured acceleration vector drifts more than 1.15 g away from a stored standing reference for 300 ms, or when its magnitude passes 2 g. The suspicion is forwarded through ESP-NOW to a second ESP32 housed in a wrist unit with an OLED screen and one button. The wearer gets ten seconds to press the button; a press discards the alert, while silence leads to a buzzer and an e-mail to the caretaker, stamped with network time. In 100 bench trials of everyday movements and staged falls, 96 decisions were correct, with 3 false alarms and 1 missed event. Radio delay between the units averaged about 6.4 ms, the wrist display reacted in roughly 120 ms, and the batteries lasted about 9 h (leg) and 13 h (wrist). Total build cost was about ₹8,000. The work suggests that asking the wearer to confirm an alert is a simple and effective way to keep an inertial fall detector from sending needless emergency messages.

Keywords: smart prosthesis, fall detection, ESP32, MPU6050, ESP-NOW, wearable alert, emergency e-mail

1. Introduction

Walking again after losing a leg is a major step towards independence, and artificial limbs make it possible for many people injured in accidents or affected by diabetes and vascular disease. The limbs most people actually wear are still purely mechanical. They carry weight and swing through a gait cycle, but they cannot sense what is happening to the wearer.

That matters because balance is harder with a prosthesis. Clinical surveys of amputees record frequent falls and a lasting fear of falling that makes people move less [1], [2]. A fall on a pavement or a staircase, with nobody nearby, can turn a bruise into a long delay before help comes.

Accelerometer-based fall detectors are a well-studied answer [3]–[5], but using them for prosthesis wearers raises three issues. A pendant or a phone does not measure the movement of the artificial limb itself. Plain threshold rules react to jumps and hard sits as readily as to falls [5]. And many designs lean on a phone, a router or a mobile network that may not be there when it is needed.

Our approach puts the sensor inside the limb, links it to a wrist unit with a router-free radio protocol, and lets the wearer veto the alert. This paper makes the following contributions:

- a shank-mounted ESP32 and MPU6050 sensing unit that decides on a fall from a sustained departure of acceleration from a stored reference posture, or from a high-g impact;
- a two-device alert chain in which the wrist unit shows a ten-second countdown and a single button cancels false alarms;
- an automatic buzzer and e-mail alert, stamped with network time, when the wearer does not respond; and
- bench measurements of accuracy, radio delay, display response and battery life on a prototype costing about ₹8,000.

Section 2 surveys earlier work, Section 3 defines the problem, Section 4 explains the design, Section 5 reports the measurements, and Section 6 closes with limitations and next steps.

2. Related Work

2.1 Artificial limbs

Artificial legs fall into two broad groups. Mechanical ones are inexpensive and robust but contain no electronics at all. Microprocessor-controlled ones, such as the Ottobock C-Leg and Össur Power Knee, adjust joint resistance or add power for a smoother gait, but they are costly and, as far as we could find, none lets the wearer confirm an emergency alert before it is sent.

2.2 Fall detection methods

Reviews of the field separate wearable, ambient and camera-based systems [3], [4]. For body-worn devices, a fixed acceleration threshold is the simplest and cheapest rule [5], though it misreads energetic daily movements. Rules that also examine body posture are more selective but depend on clean sensor data. Learning-based classifiers can be very accurate, yet they need labelled recordings and more computing power than a small battery-powered board comfortably offers.

2.3 Sensors and radio links

The MPU6050 [7] packs an accelerometer and a gyroscope behind an I²C interface and is a common choice for low-cost wearables. The ESP32 adds dual cores, Wi-Fi and Bluetooth at a low price. ESP-NOW [6] lets two ESP boards swap short packets directly, without a router. GSM modules need a SIM and a plan, while Bluetooth has limited range, so ESP-NOW suits the short leg-to-wrist hop.

Table 1. Earlier approaches compared with the proposed system

Approach	Sensor	Radio link	Wearer confirms	Auto alert	Main weakness
Phone-based detection	Phone accelerometer	Internet	No	Yes	Phone must be carried
Fitness band	Accelerometer	Bluetooth	No	Yes	False alarms
Medical wearable	IMU	Wi-Fi	No	Yes	High power use
Microprocessor prosthesis	Pressure sensor	CAN bus	No	No	Very costly
Proposed system	**MPU6050**	**ESP-NOW**	**Yes**	**Yes**	Prototype stage

2.4 Gap addressed

Taken together, the literature shows prostheses focused on movement only, detectors that cry wolf, little use of wearer confirmation, reliance on phones or routers, and few low-cost options for developing regions. The prototype described here targets those points.

3. Problem Definition and Aims

Problem. Amputees who use a prosthetic leg face a higher chance of falling, but their limb cannot report an accident. Existing wearable detectors either send alarms without asking the wearer or need connectivity that may be missing outdoors. A device is therefore required that watches limb movement continuously, lets the wearer stop a mistaken alert, and contacts a caretaker automatically when no answer comes, using little power and a fast local link.

The aims were to:

- build a motion-monitoring unit for the prosthesis around an ESP32 and an MPU6050;
- recognise acceleration deviations and impacts that go with falls;
- pass the alert to a wrist unit through ESP-NOW and show it on an OLED;
- allow a one-press cancel within the countdown;
- trigger the buzzer and an e-mail to the caretaker if nobody responds; and
- keep cost, power use and complexity low enough for further development.

4. System Design

4.1 Overview

Two independent units make up the system (Fig. 1). The **leg unit** holds the MPU6050, an ESP32 board, a piezo buzzer and a rechargeable Li-ion cell, all fixed to the metal shank of the prosthesis inside a 3D-printed shell; the sensor is oriented so gravity lies mainly along its Y axis when the wearer stands. The **wrist unit** is a second ESP32 board with a 0.96-inch SSD1306 OLED (128 × 64), a push button and its own Li-ion cell, packed in a printed case with a strap. The leg unit senses, decides, sounds the buzzer and sends the e-mail; the wrist unit receives alerts, runs the countdown and records the wearer's choice. Fig. 2 shows the built prototype.

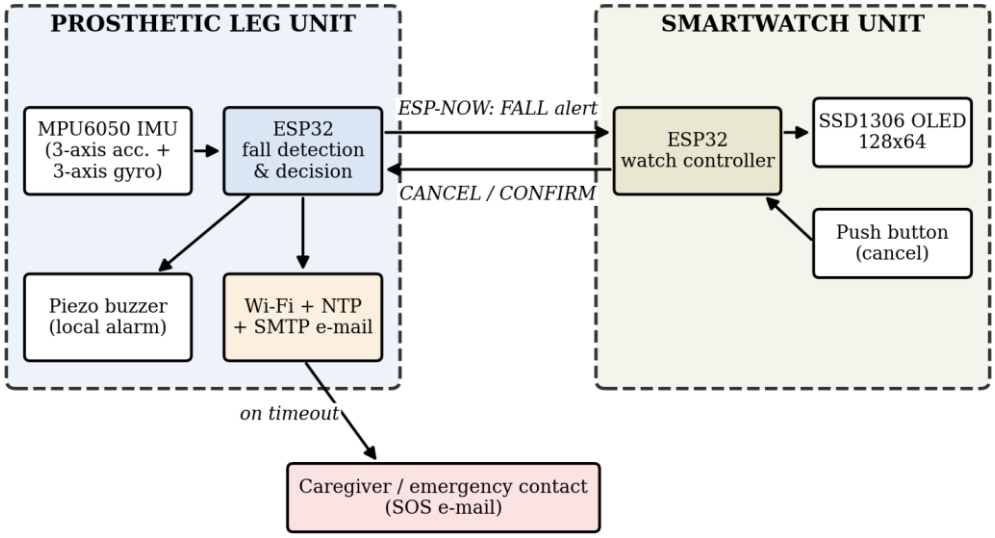
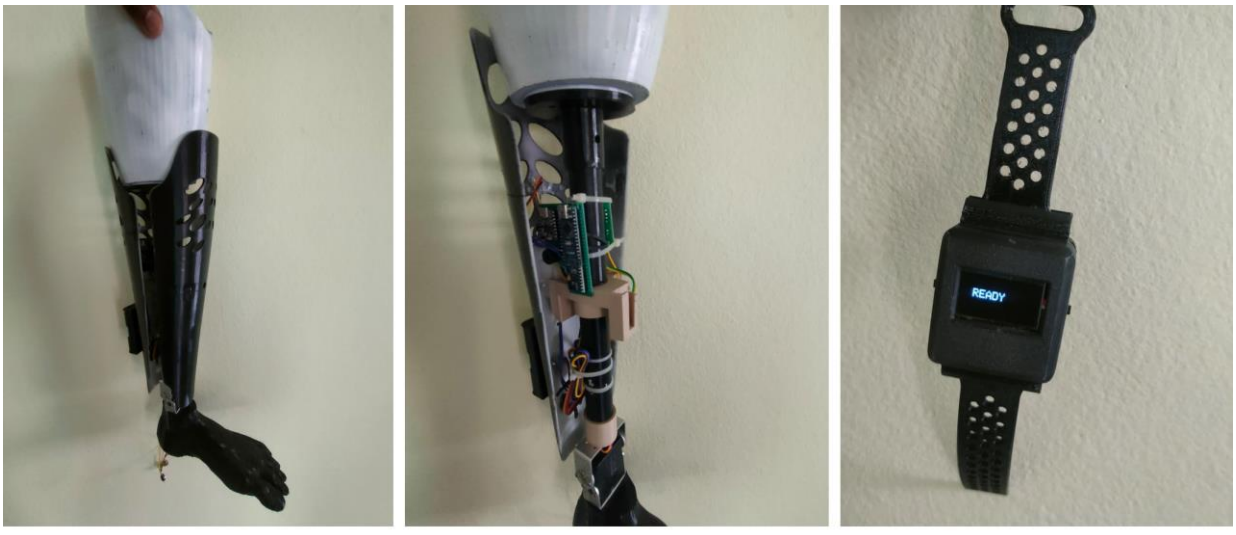


Fig. 1. Block diagram of the proposed system



(a) Prosthetic leg (b) Electronics on shank (c) Smartwatch unit

Fig. 2. Built prototype: (a) prosthetic leg, (b) electronics on the shank, (c) wrist unit

Table 2. Components and approximate cost

Item	Qty	Role	Approx. cost (₹)
ESP32 development board	2	Leg and wrist controllers	1,200
MPU6050 IMU	1	Acceleration sensing	250
SSD1306 OLED (128×64)	1	Alert and countdown display	350

Item	**Qty**	**Role**	**Approx. cost (₹)**
Push button	1	Cancel input	20
Piezo buzzer	1	Local alarm	40
Li-ion cells	2	Power	600
Charging modules	2	USB charging	200
Wiring and boards	–	Interconnection	400
3D-printed shell, foot, wrist case and mounts	–	Prosthesis structure and enclosures	3,440
Metal shank, joint hardware, fasteners	–	Mechanical frame	1,500
Total			**8,000**

4.2 Detection rule

The firmware, written in the Arduino IDE with the Wire, MPU6050, Adafruit SSD1306/GFX, ESP-NOW, ESP Mail Client and NTP libraries, takes only accelerometer data from the MPU6050. At the default ±2 g range one gram corresponds to 16384 raw counts, so every raw value is divided by 16384 to get Ax, Ay and Az in g. The gyroscope is not used in this prototype.

The acceleration vector measured while the wearer stands in a normal posture is stored as a reference (Ax_ref = 0.0765 g, Ay_ref = −1.0173 g, Az_ref = −0.0572 g). While running, two values are evaluated. The first is the distance of the current reading from that reference:

$$D = \sqrt{[(Ax - Ax_ref)^2 + (Ay - Ay_ref)^2 + (Az - Az_ref)^2]} \quad (1)$$

The second is the overall magnitude of the acceleration:

$$A = \sqrt{(Ax^2 + Ay^2 + Az^2)} \quad (2)$$

A resting limb gives A close to 1 g because of gravity. A fall is suspected if either (a) D stays above 1.15 g for 300 ms without interruption, or (b) A rises above 2 g. For (a) a timer begins when D first crosses the threshold and resets if D falls back, which filters out brief vibration. The two tests are joined by a logical OR, and a lock-out interval stops one event from firing repeated alerts. Because the rule looks at displacement from a reference rather than at vibration frequency, it is best called deviation and impact detection.

4.3 ESP-NOW messaging

The boards are paired through their MAC addresses and exchange compact ESP-NOW packets holding a header, device ID, message type, time stamp and checksum; the receiver checks each packet before using it. No router or internet is needed for this hop, which keeps delay and energy use small. The leg unit sends FALL messages, and the wrist unit answers with CANCEL or CONFIRM.

4.4 Confirmation and alert sequence

When a FALL message arrives, the wrist display reads “FALL DETECTED – Press Button” with the remaining seconds, and the buzzer sounds while a ten-second countdown runs (Fig. 3). A button press sends CANCEL, silences the buzzer and returns the system to monitoring. If the count reaches zero the wrist unit sends CONFIRM; the leg unit keeps the buzzer on, joins Wi-Fi, fetches the time over NTP and, through the ESP Mail Client library, e-mails the stored caretaker address with the date, time, device ID and an emergency message.

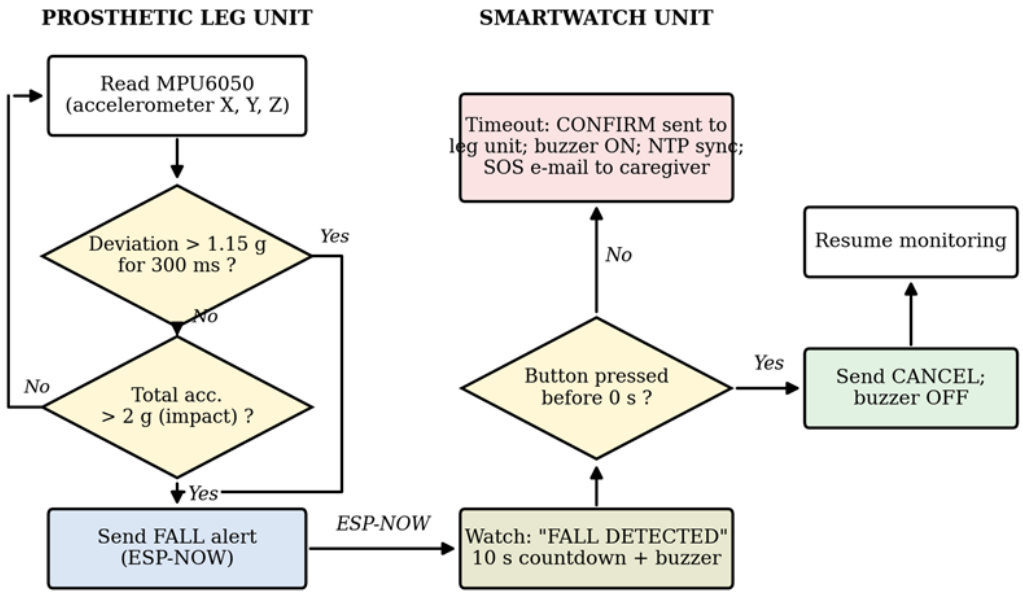


Fig. 3. Flowchart of detection, confirmation and emergency e-mail

5. Results and Discussion

5.1 Test procedure

The prototype was tested on the bench with both units paired. One tester carried out the activities in Table 3, 20–30 repetitions each and 100 trials in total. Normal, slow and fast walking, sitting, standing, stair climbing and sudden turns were expected to pass without an alert; jumping is vigorous enough to start the detector, in which case the wearer cancels on the wrist unit; a staged forward fall and a hard impact were expected to raise an alert.

Table 3. Scenarios and observed behaviour

Scenario	Expected	Observation	Result
Normal walking	No alert	Steady acceleration values; no alert	Pass
Sitting down quickly	No alert	Short acceleration rise; no alert	Pass
Jumping	Alert, then cancel	Alert and 10 s countdown shown; cancelled by wearer, no e-mail (treated as minor movement)	Pass
Staged forward fall	Alert	Thresholds exceeded; alert sent and countdown shown on wrist unit	Pass
False alarm (shake, then button)	Cancel	Alert cancelled, buzzer off, monitoring resumed	Pass
Real emergency (no response)	E-mail	Countdown expired; e-mail delivered	Pass

5.2 Detection accuracy

Ninety-six of the 100 trials were decided correctly, an accuracy of 96% (Table 4), with 3 false positives and 1 false negative. A vigorous movement that crosses the thresholds only starts the countdown; it sends no e-mail unless the wearer stays silent, which is the practical value of the confirmation step.

Table 4. Detection results (100 trials)

Trials	Correct	False positives	False negatives	Accuracy
100	96	3	1	96%

5.3 Delay, response and e-mail

Five measurements of the leg-to-wrist radio delay gave 6, 7, 5, 8 and 6 ms, about 6.4 ms on average. The wrist display updated roughly 120 ms after a packet arrived, counting reception, processing and drawing. The button press was detected, CANCEL delivered and the leg unit reset in every attempt. E-mail login, NTP sync and sending all succeeded, with delivery in about 5–8 s depending on the network.

5.4 Battery, stability and cost

On continuous use the leg unit lasted about 9 h and the wrist unit about 13 h; runtime varies with display brightness, Wi-Fi use, alarm duration and sampling. Several hours of testing caused no unexpected resets, and sensor readings, radio link and display stayed stable. Build cost was about ₹8,000 (Table 2), including the printed shell, foot and mounts, well below commercial microprocessor-controlled prostheses.

Table 5. Measured performance

Parameter	Value
Detection accuracy	96% (96/100)
ESP-NOW delay (5 trials)	≈ 6.4 ms
Wrist display response	≈ 120 ms
Cancel success rate	100%
E-mail delivery time	≈ 5–8 s
Battery life (leg / wrist)	≈ 9 h / ≈ 13 h
Build cost	₹8,000

5.5 Discussion and limitations

Joining a sustained-deviation test with an impact limit, and then asking the wearer to confirm, gave dependable detection while leaving the final decision about an e-mail with the user. The sensor sits on the limb that actually takes the fall, and the local link needs no router. Several limits apply: testing was brief, on a bench, and by one person; 100 trials is a small sample and the delay figure rests on five readings; the thresholds (1.15 g for 300 ms, and 2 g) and the reference posture would need tuning for each wearer; the e-mail needs Wi-Fi; and the prototype does not yet use the gyroscope, location, heart-rate data or a learned classifier.

6. Conclusion and Future Work

We presented a prosthetic leg that notices possible falls with an ESP32 and MPU6050, asks the wearer to confirm on an ESP-NOW-linked wrist unit, and e-mails a caretaker automatically if there is no answer. On the bench it reached 96% correct decisions with about 6.4 ms link delay and about 120 ms display response, for roughly ₹8,000.

Next steps are GPS and cellular modules so alerts carry location without Wi-Fi, use of the gyroscope together with a light machine-learning model and per-user calibration, extra sensors for gait and health monitoring, a phone app with cloud logs, and trials with amputee volunteers under clinical supervision.

Achievement:

The prototype was also entered in the Project Competition of IMPETUS 2K26, a national-level technical event held at Sharad Institute of Technology College of Engineering, Yadrav, on 15 October 2026 in association with the ISTE Student Chapter and IQAC, where it won the First Prize.

Acknowledgement:

The authors thank their guide, Dr. S. Y. Salunkhe, and the Department of Mechatronics, Sharad Institute of Technology College of Engineering, for guidance and laboratory facilities.

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