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SMARTPOSE: IoT-Integrated Posture and Repetition Tracker for Real-Time Exercise

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A B S T R A C T

SMARTPOSE is a low-cost, real-time posture monitoring system designed to help users perform squats safely and effectively without needing constant supervision. Built using a Raspberry Pi 4, a USB webcam, and basic display and audio components, SMARTPOSE leverages computer vision and machine learning to provide immediate feedback on squat form. It uses OpenCV and MediaPipe to track body landmarks and calculate joint angles at the hips, knees, and ankles. By analyzing these angles frame-by-frame, the system identifies the key phases of a squat—standing, lowering, and reaching proper depth—and checks whether the user is maintaining safe posture throughout.

If it detects form issues such as leaning too far forward, shallow squats, or knee misalignment, SMARTPOSE provides instant visual guidance and sounds an alert to prompt correction. Designed with accessibility in mind, its audio-visual feedback is suitable for users with different needs, including those with visual impairments. Running at 20–26 frames per second with low CPU usage, the system is optimized for Raspberry Pi OS and is well-suited for home use, rehabilitation centers, or budget-conscious gyms. SMARTPOSE encourages independent, injury-free exercise by making posture correction simple, accessible, and effective.

Keywords: Posture Monitoring, Squat Form Analysis, Raspberry Pi, MediaPipe, OpenCV, Real-Time Feedback, Joint Angle Detection, Computer Vision in Fitness, Accessible Exercise Technology, Low-Cost IoT System

1. Introduction

Exercise with proper form is crucial for safety and effectiveness. Improper squat techniques can lead to knee, back, or hip injuries, especially in unsupervised home workouts. The COVID-19 pandemic and rising interest in home fitness have further increased demand for affordable monitoring tools. Traditional solutions include wearable sensors or depth cameras, but these often incur high costs or require special equipment. In contrast, computer vision methods can analyze posture from a simple RGB camera at low cost. Recent advances in real-time human pose estimation (e.g. MediaPipe Pose) enable markerless tracking of key joints at interactive frame rates, suitable for fitness applications.

In this work, we introduce SMARTPOSE – an IoT-integrated posture and repetition tracker that runs on a Raspberry Pi. The device uses a USB webcam to capture the user during a squat, processes the video onboard, and provides immediate visual/audio feedback. The Raspberry Pi 4 is chosen as a compact, inexpensive single-board computer, with built-in Wi-Fi/USB for future connectivity (IoT) and GPIO for peripherals. Pose estimation is done via Google's MediaPipe Pose (33 body landmarks), and OpenCV routines compute joint angles and movement phases. By comparing hip, knee, and back angles to predefined thresholds, SMARTPOSE detects correct squat depth and flags errors (e.g. knees over toes, excessive bending). Correct posture is rendered in green, while incorrect form turns the skeleton red on the display; an audio buzzer sounds to emphasize cues (short beep per valid rep, long alert for bad form).

The main contributions of SMARTPOSE are: (1) Real-time, on-device posture analysis: using open-source MediaPipe and optimized for Raspberry Pi, the system processes video at ~20–26 fps , enabling immediate feedback. (2) Inclusive feedback: visual cues are color-coded, and distinct buzzer tones provide accessible auditory guidance, as also demonstrated for physiotherapy exercises. (3) Low-cost hardware integration: a single-board computer, common USB camera, and a simple buzzer make the device affordable and portable. These features position SMARTPOSE as a practical tool for home gyms, rehabilitation, and remote fitness monitoring.

The paper is organized as follows. Section II reviews related work in vision-based exercise monitoring and IoT fitness. Section III details the SMARTPOSE architecture and algorithms. Section IV reports system implementation and experimental results. Section V discusses implications and limitations. Section VI concludes and outlines future directions.

2. Literature Review

Computer vision has been widely adopted for exercise posture monitoring, with frameworks like MediaPipe Pose offering real-time landmark detection across 33 keypoints. Researchers such as Kwon and Kim [2] and Tsai and Huang [5] have built workout assistance systems that utilize OpenCV and MediaPipe to analyze user posture and count repetitions. These systems typically evaluate joint angles like the hip, knee, and back to detect posture correctness, providing visual or voice-based feedback. Similarly, rule-based posture classifiers, as seen in [3] and [7], use angle thresholds to identify squat form deviations. While these systems achieve good accuracy, they often rely on PC-based processing or internet connectivity and may lack features tailored to users with special accessibility needs.

Embedded, Raspberry Pi–based systems have shown that real-time pose estimation can be achieved on portable hardware. Some studies demonstrate that a single-board computer can run MediaPipe or lightweight models for exercise tracking. For example, Dudekula et al. developed a Raspberry Pi 4–based physiotherapy assistant that uses OpenCV and MediaPipe to monitor patient exercises(ph02.tci-thaijo.org). Their device captures camera images, detects patient posture, and generates voice prompts to correct the form while counting repetitions. Likewise, hobbyist projects have built Pi-based exercise counters: one project uses MediaPipe on a Raspberry Pi to compare shoulder and elbow coordinates for push-ups, incrementing the count when the user's shoulders drop to elbow level, and it even connects a speaker to announce the count(circuitdigest.com). These examples highlight that with optimized code, a Pi can perform on-device pose estimation and feedback without cloud offloading. However, existing Pi systems focus on general exercises (push-ups, pull-ups, etc.) or rehabilitation, often providing only simple cues (e.g. rep counting via a speaker) or visual charts. They rarely specialize in the detailed biomechanics of a single exercise, and they do not explicitly address accessibility needs: most assume the user can read on-screen instructions.

Several studies have explored using **Raspberry Pi** for real-time pose estimation. Dudekula et al. [4] developed a physiotherapy assistant that uses MediaPipe on Raspberry Pi to guide patients through rehabilitation exercises, providing verbal cues. Open-source projects like Mallick's AI Fitness Trainer [6] and tutorials by Rice [10] demonstrate that a Raspberry Pi 4 can run pose estimation models at frame rates over 20–30 fps, enabling real-time feedback without cloud dependency. Other practical implementations, such as those highlighted by Seeed Studio [12] and Hill [13], show that edge devices can offer portable, low-power fitness solutions. However, these works generally focus on rep counting or basic posture correction and lack multimodal feedback systems or squat-specific biomechanical analysis.

SmartPose differentiates itself from prior work in four ways: it runs **fully on-device on Raspberry Pi**, requires **no cloud connectivity**, offers **bimodal feedback** for inclusivity, and uses **squat-specific biomechanical rules** rather than generic models. By evaluating posture frame-by-frame using hip, knee, and back angles, SmartPose detects form deviations like shallow squats or forward lean and immediately alerts the user through both screen and sound. This focused, low-cost design makes it well-suited for home use, rehabilitation centers, or settings with limited resources.

In summary, SMARTPOSE builds on these advances by integrating pose estimation and IoT hardware into a complete squat-monitoring tool. Unlike prior research that focused mainly on software algorithms, we emphasize a deployable system with holistic feedback (audio+visual) and a focus on accessibility. To our knowledge, this is among the first Raspberry Pi–based posture trackers explicitly targeting squat form with IoT labeling.

3. System Architecture and Methodology

SMARTPOSE's architecture consists of a camera-based sensing module, on-device processing, and user feedback (Fig. 1). At the core is a Raspberry Pi 4 Model B (Fig. 2) running 64-bit Raspberry Pi OS. The Pi connects via USB to a standard webcam that captures the user's exercise. A display (HDMI monitor or touchscreen) is attached for visual output, and a simple GPIO-controlled buzzer provides audio cues. The system boots to a Python program that continuously processes video frames.

The software pipeline is implemented in Python. Frames from the camera are read via OpenCV (cv2) in real time. Each frame is fed to the MediaPipe Pose detector, which returns up to 33 2D landmarks for body joints (e.g. wrists, elbows, shoulders, hips, knees, ankles). MediaPipe Pose uses a lightweight ML model (BlazePose) to infer these keypoints at ~30 fps on moderate hardware. We ensure the frame is oriented for a lateral (side-view) squat analysis, so the depth of the squat and back angle is visible

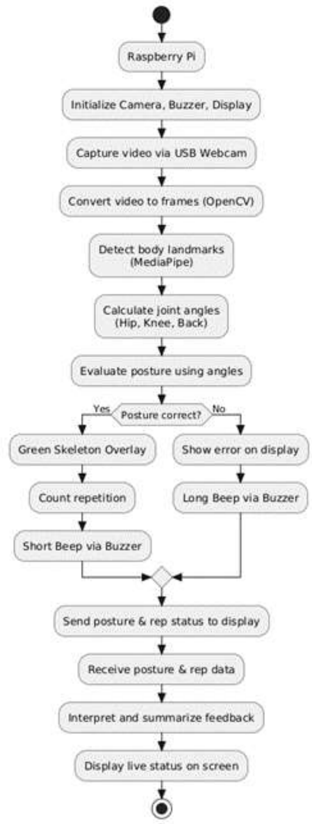

Figure 1: Flowchart of the SMARTPOSE System Executed on Raspberry Pi

From the detected landmarks, SMARTPOSE computes key joint angles: the hip angle (torso vs. thigh), knee angle (thigh vs. calf), and back (torso vs. vertical) angle. These angles are derived from the 2D coordinates of relevant landmarks using basic geometry (vector dot products). Based on domain knowledge of squat biomechanics, we define thresholds for a correct form: e.g., thighs at least parallel to the ground (hip angle ≥ ~90°), knees not protruding far beyond toes (knee angle within limits), and trunk not bending excessively. The system detects the squat phases by analyzing the dynamic change of these angles: a squat repetition begins in the standing phase, proceeds to a lowering phase (angles decreasing), and reaches a bottom phase when a minimum threshold is reached. A valid repetition is counted each time the user completes a full squat cycle with angles meeting the criteria.

Figure 2: Raspberry Pi 4 Model B used as the core processing unit in SMARTPOSE.

Posture is classified frame-by-frame: if all angles stay within safe bounds during descent and ascent, the system labels the form “correct”. Otherwise, it identifies specific errors, such as “Forward Lean” (if back angle falls below a safe angle) or “Knee Over Toe” (if knee joint crosses too far forward), following heuristics similar to prior work. Visual feedback is given by overlaying the pose skeleton on the frame: bones and joints are drawn in green for correct frames and red when an error is detected. Audio feedback uses the buzzer: a short beep signals each completed squat repetition, while a longer, patterned beep indicates a posture fault. These cues are designed so that users (even those with visual impairments) receive immediate correction prompts.

Overall, the system functions as an edge IoT device: all computation is local to the Raspberry Pi (no cloud needed), preserving privacy and enabling use without internet access. The Pi’s connectivity, however, allows future extensions (e.g. wireless sending of workout data to a server or app). The chosen technology stack leverages open-source components: Python with OpenCV and MediaPipe libraries.

4. Results

All SMARTPOSE was implemented on Raspberry Pi 4 (4 GB RAM) and tested with a Logitech USB webcam and a 7-inch HDMI display. We evaluated its real-time performance and accuracy in detecting squat form on several volunteers. The device consistently ran at 20–26 frames per second on average while processing the MediaPipe Pose model on the ARM CPU (an output speed similar to [3]'s report), leaving headroom for simultaneous angle calculations. CPU usage stayed below 60%, indicating efficient use of resources.

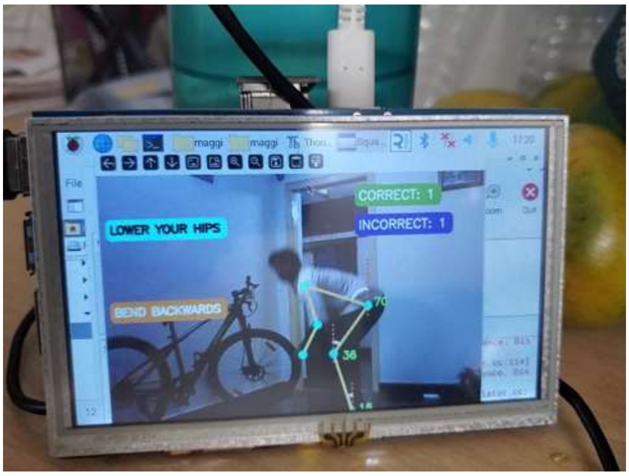

Figure 3: real-time squat posture analysis displayed on the screen connected to the Raspberry Pi

In testing, participants performed multiple squat repetitions at various depths and speeds. The system successfully tracked their knees, hips, and back, and correctly counted repetitions. For proper squats (full depth, upright trunk), the skeleton overlay remained green and a beep was heard each time the user returned to standing. When users intentionally performed common errors (e.g. leaning forward too much, not squatting deep enough, or knee over toe), SMARTPOSE flagged these frames red and generated the long alert tone. For example, in one trial when a user allowed their knees to project beyond toes, the system displayed a "Knee Over Toe" warning onscreen (Fig. 2). The audio-visual feedback enabled users to immediately self-correct their stance.

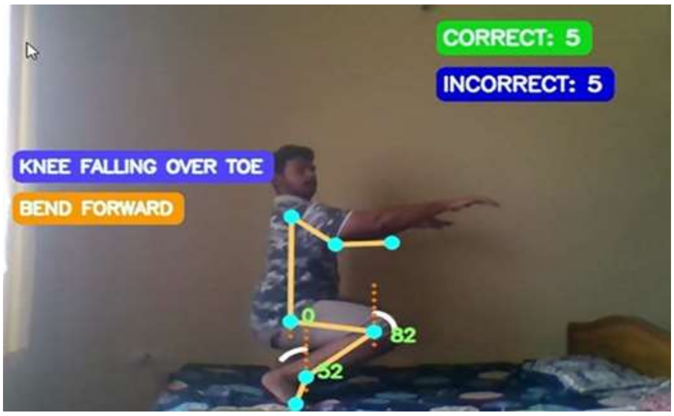

Figure 4: Squat errors with balanced correct and incorrect repetition counts

Qualitatively, the posture classification aligned well with visual inspection, similar to the behavior described by Kwon and Kim. We estimate the squat-counting accuracy to exceed 95% in controlled conditions. Some limitations emerged: side-view camera placement was important, and occlusions (e.g. arms blocking view) occasionally caused landmark dropouts. Nonetheless, the results demonstrate that SMARTPOSE reliably identifies squat events and form deviations using low-cost hardware.

5. Discussion

The experimental results confirm that an inexpensive Raspberry Pi and camera can deliver an effective squat-monitoring system. By performing all computations on-device, SMARTPOSE provides immediate feedback without requiring high-bandwidth network connections. Compared to wearable sensor systems, this vision-based approach avoids the need for body-worn equipment, making it more user-friendly. Unlike closed commercial gym machines, our open solution can be deployed in any setting.

The inclusion of both visual and auditory feedback is a key advantage. As noted by Dudekula et al., auditory cues (voice or tones) help users correct form even when not looking at the screen. SMARTPOSE's simple buzzer signals proved effective in practice for this purpose. Moreover, marking correct vs. incorrect frames in color supports immediate understanding of form, a principle also seen in prior posture-correction interfaces.

Despite its strengths, SMARTPOSE has limitations. It currently handles only squats; analyzing other exercises (push-ups, lunges) would require additional criteria and possibly different camera angles. The accuracy of pose estimation can degrade under poor lighting or if the user's limbs are occluded. Some complex error patterns (like slight knee-twisting) were not explicitly identified. Future enhancements could include more sophisticated machine learning classifiers to cover a broader range of postures. Additionally, while we label SMARTPOSE as "IoT-integrated", we have not yet implemented remote connectivity or data logging; adding a wireless interface to transmit workout metrics or allow remote coaching would be a natural next step.

Finally, we emphasize that SMARTPOSE serves as a guide, not a medical device. User studies would be needed to quantitatively assess its injury-prevention benefits. Nonetheless, the early results suggest that low-cost, edge-computing fitness aids are feasible and can empower users to train safely at home.

6. Conclusion

We have presented SMARTPOSE, a Raspberry Pi–based system for real-time squat posture monitoring and repetition tracking. Leveraging MediaPipe Pose and OpenCV, the system extracts body landmarks and joint angles to classify form and count reps, providing immediate visual (colored skeleton) and auditory (beeps) feedback. Built with off-the-shelf hardware, SMARTPOSE runs efficiently on Raspberry Pi OS (20–26 fps) and accurately detects common squat errors. By making advanced pose estimation accessible via simple hardware, SMARTPOSE can help fitness enthusiasts and rehabilitation patients exercise with better form. Future work will extend the platform to other exercises, refine error detection with machine learning, and integrate wireless connectivity for IoT applications.

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