Guitar-Pal: Smart Guitar Learning Assistant

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I. Introduction

Learning to play the guitar presents significant challenges for beginners, often leading to high dropout rates and diminished motivation. Studies indicate that approximately 90% of novice guitarists abandon the instrument within their first year [1], primarily due to difficulties in mastering finger placements, limited real-time feedback from static diagrams or instructors, and the steep early learning curve. Traditional tutorials and mobile applications, while accessible, frequently lack physical, interactive guidance, resulting in slow muscle memory development.

This project introduces Guitar-Pal, an embedded system designed to provide visual, real-time assistance directly on the guitar fretboard. The aim is to create an affordable, user-friendly tool that accelerates skill acquisition for beginners. Key objectives include implementing LED-based chord and scale illumination controlled via a mobile application, establishing Bluetooth Low Energy (BLE) connectivity for seamless interaction, and planning advanced features such as finger position detection and a mobile-app-based tuner to enhance the learning experience.

II. Literature Review

Existing research on interactive guitar learning tools highlights the potential of embedded systems and augmented interfaces to improve music education. An embedded system integrated with a smartphone application that lights LEDs on the fretboard to guide practice without sheet music has been proposed, focusing on chord and note visualization, but still lacks of feedback [2]. Augmented reality approaches overlay visual tutorials on the instrument, providing interactive lessons with fret highlighting and 3D hand overlays. Additional AR-based applications use 3D models and animated hands to teach chords and transitions on acoustic guitars [3].

Commercial tools such as the Fretlight guitar and apps like Yousician provide LED guidance or gamified lessons, but often require proprietary hardware or lack open-source customization. A gap exists in affordable, DIY-embedded solutions that combine physical LED integration with mobile control and touch-sensitive feedback, justifying the development of Guitar Pal to address accessibility and engagement for beginners.

III. Materials and Methods

A. Hardware Design

The hardware consists of the following components [Fig. 1]:

- **ESP32:** Acts as the main controller, powered by a 5V supply, managing LED illumination, BLE communication, and sensor inputs via its GPIO pins.
- **WS2812B LED Strips:** Individually addressable LEDs positioned along the fretboard to provide precise visual cues for chords and scales.
- **Electrode Grid for Finger Position Recognition:** A planned grid leverages the conductive properties of guitar strings and frets. Each string receives periodic high-voltage signals from the ESP32, while frets are connected to dedicated GPIO pins. A finger press closes the circuit at the intersection, and the ESP32 sequentially scans strings (multiplexing voltage) while reading GPIO inputs to detect positions for real-time feedback.
- **Power Supply:** The system is powered by a rechargeable battery pack, providing power for the LED strips and for the electrode grid.

The overall system architecture integrates these hardware elements with software modules for UI, pattern lighting, and calculations.

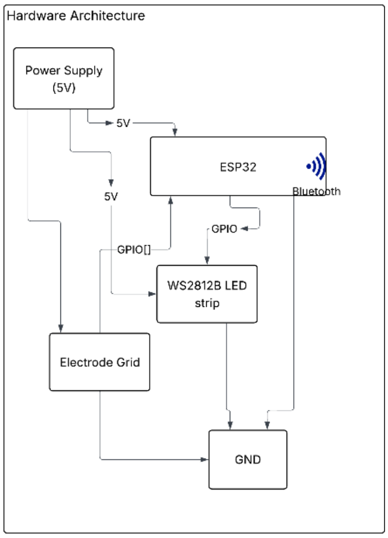

Fig. 1. Hardware Architecture of Guitar-Pal

B. Software Design

The software consists of the following components [Figure 2]:

Firmware: Software development for the ESP32 firmware was conducted using PlatformIO in VS Code, incorporating the *FastLED* library for efficient LED control and *BLE* protocols for wireless data exchange. BLE connectivity is established using the ESP32's built-in module, enabling low-power, reliable communication with the mobile app for command transmission and data feedback, such as finger position verification. Chord and scale positions are calculated algorithmically to map musical notes to specific LED indices, ensuring accurate and dynamic lighting patterns.

Mobile Application: The companion mobile application, developed in Flutter using Dart for the easy adaptation to both android and iOS mobile phones, provides an intuitive user interface for selecting chords, scales, or songs, as well as tuning assistance. Commands are transmitted via BLE to the ESP32, triggering the corresponding LED illuminations and receiving sensor data for corrective feedback within the app.

C. Fret LED Grid Mapping to the 8x8 LED Matrix

For initial prototyping and testing of LED control logic, an 8x8 WS2812B LED matrix was employed to simulate the guitar fretboard. The matrix mapped 6 strings across 8 frets (utilizing 6 columns and leaving 2 spare for diagnostics), with LED indices arranged in a serpentine pattern to replicate the continuous strip layout on the actual hardware. Algorithmic mapping via FastLED translated chord/scale calculations to matrix positions, verifying pattern accuracy before full fretboard deployment [Figure 3].

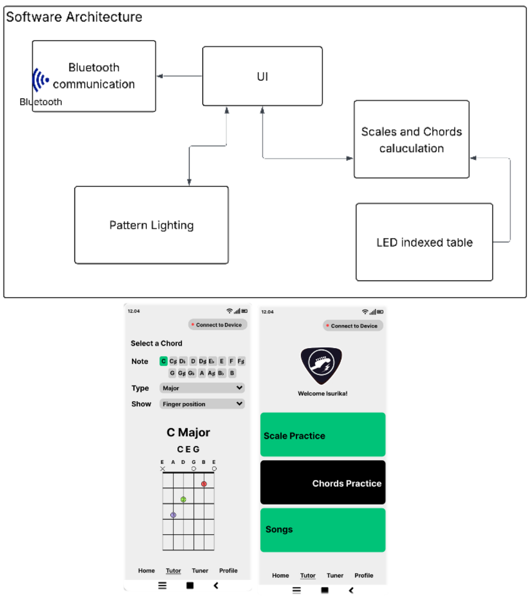

Fig. 2. Software Architecture of Guitar-Pal and Mobile application UI

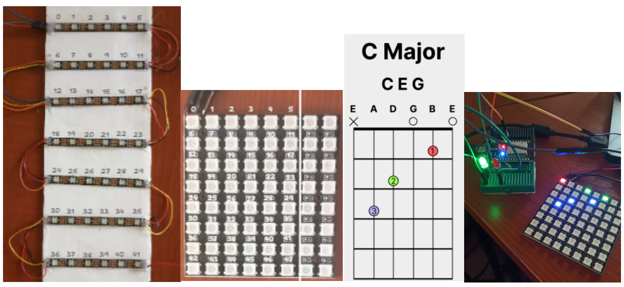

Fig. 3. Fret board POS, 8x8 LED matrix mapping, Chord visualization in the mobile app, Fret board LED visualization in LED 8x8 matrix

IV. Results and Discussion

The complete implementation demonstrates chord and scale selection features, with users selecting options via the mobile app to trigger real-time LED illumination on the fretboard—for example, lighting specific positions for a C major chord or pentatonic scale. BLE connectivity ensures reliable, low-latency data transmission, with LED patterns calculated accurately based on fretboard mapping. Finger position detection provides immediate feedback, comparing user placements against guided patterns. The tuner accurately detects string frequencies for precise tuning, and song mode offers step-by-step guidance for full songs.

Challenges included selecting suitable narrow LED strips to fit between frets and ensuring safe voltage levels for the electrode grid to avoid interference. These were addressed through iterative testing, resulting in a responsive system that enhances visual and tactile feedback compared to static methods. Demos show improved user engagement, potentially reducing dropout rates by facilitating faster muscle memory. Discussion highlights Guitar Pal's advantage over existing tools by offering open-source, low-cost integration with comprehensive features.

V. Conclusion and Future Work

Guitar Pal achieves its objectives of providing interactive LED guidance for chords, scales, and songs, along with finger detection and tuning, demonstrating a viable embedded solution for beginner guitarists. The system addresses key learning barriers, with the potential to lower the 90% annual dropout rate through engaging, physical assistance.

Limitations include dependency on BLE range and battery life. Future directions involve integrating the finger position detection, tuner, sound output, and song tutorials for a comprehensive tool. This research paves the way for scalable music education devices.

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