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Braive: IoT Enabled Smart Braille Learning Glove for Assistive Education

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Abstract: Learning Braille is essential for visually impaired children, yet trained teachers and affordable tactile learning tools are scarce. This paper presents Braive, an IoT-based Braille learning system that pairs a wearable glove with an Android application over Bluetooth Low Energy (BLE). An ESP32 in the glove drives six vibration motors arranged as the dots of a Braille cell and reads six tactile switches for input. The Kotlin application offers a Learning Mode, a five-level gamified Practice Mode with an adaptive question generator, and a word-spelling Test Mode, while speech recognition, text-to-speech feedback and an on-device Room database allow fully offline operation. BLE latency, recognition accuracy and learning outcomes were not measured, and no study with visually impaired learners has yet been carried out. The two-part architecture keeps lesson logic on the phone and real-time actuation on the glove, providing a modular, low-cost approach to Braille education built from commodity components.

Keywords: Braille learning, smart glove, Internet of Things, ESP32, Bluetooth Low Energy, haptic feedback, assistive technology, Android application

I. INTRODUCTION

Learning Braille is one of the most important milestones for a visually impaired child, because it opens the way to independent reading, writing and communication. In practice, many children who need Braille lack access to trained teachers, and the tools that do exist are either expensive or not engaging enough for young learners. Refreshable Braille displays and note-takers can cost from tens of thousands to lakhs of rupees and are designed mainly for adults who already read Braille, while most mobile learning applications depend on a flat touchscreen and give no sensation of raised dots. Traditional teaching with a slate, stylus and embossed books works well only where a qualified teacher is available.

Earlier work has examined haptic feedback, wearable and glove-based devices, gamification and voice interfaces, but mostly one at a time. Combining embedded computing, wireless communication, haptic output and a mobile application provides an opportunity to build a learning aid that is affordable and usable without sight, a teacher or an internet connection.

This work presents Braive, a smart Braille learning system made of a vibrating glove and an Android application. The ESP32 in the glove drives six vibration motors and reads six tap switches, while the application, acting as the BLE client, holds the lessons, runs the quiz logic and handles speech. The system provides Learning, Practice and Test modes with adaptive, gamified practice and local progress tracking, and operates entirely offline. Two-way tap input, spoken feedback and per-letter accuracy tracking are intended to keep young learners engaged.

II. LITERATURE SURVEY

Previous studies on Braille education technology have focused on low-cost IoT hardware, wearable haptic devices, learning applications, and refreshable or recognition-based systems. These approaches aim to make Braille learning more accessible and less dependent on trained teachers.

A. *Low-Cost and IoT-Based Systems*

Low-cost and IoT-based devices show that affordable hardware can support Braille education. Joshi et al. [1] built a smart learning kit from inexpensive sensors and actuators, Atta and Adu-Labi [4] designed an interactive device for children in resource-limited settings, and Smajić et al. [6] used IoT connectivity for Braille input and translation. These works are limited in interactivity or concentrate on translation rather than teaching.

B. *Wearable and Glove-Based Systems*

Wearable and glove-based systems add tactile or voice feedback. HapticGuide [2] delivers wearable haptic Braille, a glove-based writer gives voice confirmation of input [3], and a wrist-worn device supports classroom learning [16]. Gloves have also been used beyond Braille, for banknote recognition [9] and RFID-based object identification [20]. Most of these emphasize input or sensing more than guided, self-paced learning.

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C. *Learning Applications, Displays and Recognition Systems*

Learning-oriented studies show that well-designed haptic feedback speeds up Braille recognition for beginners [7] and that gamification improves motivation and retention [21]. Other applications provide interactive learning [19], text-to-Braille conversion [13] or standard-based teaching [18], but a smartphone-only haptic application lacks realistic tactile feedback [5]. Refreshable and actuated displays give accurate dynamic output [8], including voice-controlled solenoid devices [11] and deep-learning displays that adapt to the learner [15], but they are expensive, bulky or complex. A further group concentrates on recognition rather than teaching, using wearable motion sensors [10], convolutional networks [12], YOLOv8 [14] or deep learning for users with dual impairment [17].

D. *Research Gap*

Although previous studies address low-cost hardware, wearable haptic output, gamified learning and voice interfaces, integrating these capabilities into a single system remains a practical challenge. Among these 21 works, none combines a low-cost wearable tactile output, two-way tap input, a voice interface, adaptive gamified practice and offline operation for children in a single system. The proposed system combines an ESP32-based vibrating glove with an Android application that provides these capabilities together.

III. PROPOSED SYSTEM

The proposed system is a smart Braille learning system in which a wearable glove and an Android application stay in sync over BLE. The prototype supports free exploration of letters, gamified adaptive practice and a word-spelling test for Grade-1 English Braille. Its major subsystems include power, control, haptic output and tap input, software, learning modes, and BLE communication.

A. *Power Subsystem*

A rechargeable BL-5C lithium-ion cell supplies the glove through a rocker switch and an LM2596 buck converter. The ESP32, the motor driver board and the battery share a common ground. The firmware reports a simple low-battery flag rather than a charge percentage.

B. *Control Subsystem*

The glove is built around an ESP32-DevKitC-32D, which acts as the BLE GATT server. The firmware is written in the Arduino IDE using the Arduino-ESP32 BLE libraries. It receives vibration patterns from the application, drives the motors, reads and debounces the tap switches, and notifies the application of tapped dots. The Android application acts as the BLE client and holds the lessons, the quiz logic and the speech interface.

C. *Haptic Output and Tap Input Subsystem*

Six cylindrical vibration motors, one per Braille dot, represent the pattern of a letter on the glove. Because GPIO pins cannot drive the motors directly, each motor has its own driver stage consisting of a 2N2222 transistor, a 1 kΩ base resistor and a 1N5819 diode that absorbs the voltage spike when the motor switches off. Six tactile push-button switches, one per dot, are mounted at the fingertips and palm and read through the ESP32's internal pull-up resistors, so a tap pulls the pin low. Switches use GPIO 13, 12, 14, 27, 26 and 25 and motors use GPIO 18, 19, 21, 22, 23 and 32 for dots 1 to 6.

D. *Software Subsystem*

The application is written in Kotlin 2.1.20 for Android API 36 with a minimum of API 24, using the MVVM pattern, View Binding and the Navigation Component. Room 2.7.0 stores letter definitions, level configuration and each child's per-letter accuracy and progress on the device. Coroutines run database, BLE and speech work, and Lottie and a low-latency SoundPool provide animations and correct/wrong sounds. A SpeechManager wraps SpeechRecognizer and TextToSpeech, with speech slowed to 0.85× for young learners. A Braille engine holds the Grade-1 alphabet A–Z as six-element patterns and builds the vibration payload, a spoken description such as "dots one, two, four and five", and the validation of answers. A phonetic alias table maps how letters are actually transcribed, for example "bee" for B, because a speech recognizer rarely returns a bare letter. Controls carry content descriptions for TalkBack, all data stay on the device with no accounts or cloud synchronization, and the application requests only Bluetooth, microphone and location permissions (location is required by Android for BLE scanning).

E. *Learning Modes and Adaptive Practice*

Learning Mode lets the child tap or say any letter A–Z; the pattern is vibrated, the letter and its dots are spoken, and the letter is recorded as learned. Practice Mode groups the alphabet into five levels (A–E, F–J, K–O, P–T and U–Z) of ten questions each, with three lives, a score and stars. In one question type the glove vibrates a pattern and the child says the letter, and in the other the application speaks a letter and the child taps its pattern on the glove. Test Mode speaks a word and the child taps each letter's dots in sequence, ending with an accuracy percentage.

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The practice generator uses each letter's stored accuracy to decide how often it may appear, so weak or unattempted letters are repeated more than mastered ones. It alternates the two question types and shifts gradually toward the harder one, in which the child reproduces a pattern from memory, as a session proceeds. A small review pool reserves slots for letters from completed levels, and a letter answered incorrectly is requeued a few questions later. Every selection passes through the same lookup, vibrate, speak and record pipeline, so attempts in any mode update the same accuracy data.

F. *BLE Communication Subsystem*

Each Braille character is encoded as a six-byte array, one byte per dot, and written to the glove. The ESP32 exposes three characteristics: one written by the application with vibration patterns, one that notifies the application of tapped dots, and one carrying a low-battery flag. A BleManager scans, connects, subscribes to notifications and places every GATT operation in a queue, because Android's BLE stack handles one outstanding operation at a time and a second command sent too early can be silently lost. The glove reports only which switches are pressed at that instant, so a multi-dot answer is assembled in the application: each new one-dot notification is combined into a running pattern, and the answer is finalized after a 1.5 s pause following the last new tap. A tap that never settles within 15 s is treated as no answer.

IV. RESULTS AND DISCUSSION

The proposed system was evaluated through staged software testing and functional testing of the integrated glove and application on a physical Android phone, because the emulator cannot reproduce the BLE connection reliably. The evaluation covered Braille encoding, speech matching, storage, question selection, BLE communication, practice and test sessions, and the user interface. The results demonstrate the operation of the major subsystems, although BLE latency, recognition accuracy and learning outcomes have not been quantitatively evaluated.

A. *Unit Test Evaluation*

Testing was carried out in stages: unit, integration, functional, system and acceptance. All ten unit-level test cases produced the expected result. They covered the dot pattern lookup for every letter A–Z, vibration payload construction, spoken dot descriptions, phonetic matching of spoken letters, tap validation, the database round trip of a six-dot pattern, the repetition weight of weak letters, the mix of question types late in a session, and the recording of attempts. Their outcomes are summarized in Table I.

B. *Integrated System Performance*

Integration testing paired the application with the glove on a Redmi 13 5G phone. A vibration command from the BLE manager reached the correct motor pins, and a tap on the switches was debounced and reported back to the application. Repeated runs confirmed that the operation queue prevented the silent loss of the two notification subscriptions made immediately after connecting, and tapping dots one at a time with pauses showed that the application waited for the 1.5 s settle time instead of accepting a partial answer.

In system testing a complete Practice session was played from level selection to completion. The generator mixed new, weak and review letters; letters answered wrongly returned about four questions later; and stars and unlock state were written to the database and shown in the level grid. Several Test Mode attempts produced a final accuracy that matched a manual count of correct taps. Unrecognized speech returns no match rather than a wrong guess. Acceptance testing was qualitative: a mode could be chosen from the home screen without explanation, vibrations were distinct on separate fingers, narration at 0.85× speed was clear enough to follow, and the application stayed usable without the glove by showing and speaking the pattern. The results are summarized in Table I.

TABLE I TEST CASE VERIFICATION

Test	Observation	Assessment	Status
Braille encoding (T1–T3)	Lookup for A–Z; six-byte payload; dots of G spoken	Patterns, payload and spoken dots correct	PASS
Speech matching (T4–T5)	"bee" resolves to B; "the letter zed" resolves to Z	Aliases and prefix stripping work	PASS
Tap validation (T6)	Correct tapped pattern checked	Accepted as correct	PASS
Data storage (T7)	Six-dot array saved and read back from Room	Identical array restored	PASS
Question selection (T8–T10)	Weak-letter weight; recognition-question chance; attempt recording	Weak letters repeated more; counts updated correctly	PASS
BLE glove integration	Command reached motor pins; taps debounced and reported	Two-way exchange functional	PASS

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Test	Observation	Assessment	Status
Multi-dot tap assembly	Dots tapped one at a time with pauses	Waited for 1.5 s settle time	PASS
Practice session	Full session from level selection to completion	Wrong letters requeued; stars and unlocks saved	PASS
Test Mode	Several spelling attempts	Accuracy matched manual count	PASS

C. *Prototype and Mobile Application*

The completed prototype is shown in Fig. 1. The photograph shows the glove with its vibration motors and tap switches wired to the ESP32 unit. The ESP32 provides BLE communication and hardware control, while the rechargeable battery supplies the glove.

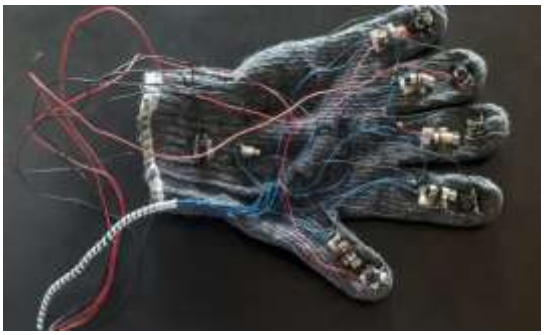


Fig. 1 Completed Braive glove prototype with vibration motors and tap switches wired to the ESP32 unit.

The mobile application screens are shown in Fig. 2. The interface is dark and high-contrast with large buttons. The home screen shows the glove connection state and the three mode buttons. Learning Mode shows the selected letter, a six-dot grid and an A–Z keypad with a voice button. Practice Mode locks each level until the previous one is passed and, during a session, shows question number, lives and score. Test Mode shows the word being spelled and the letter currently expected.

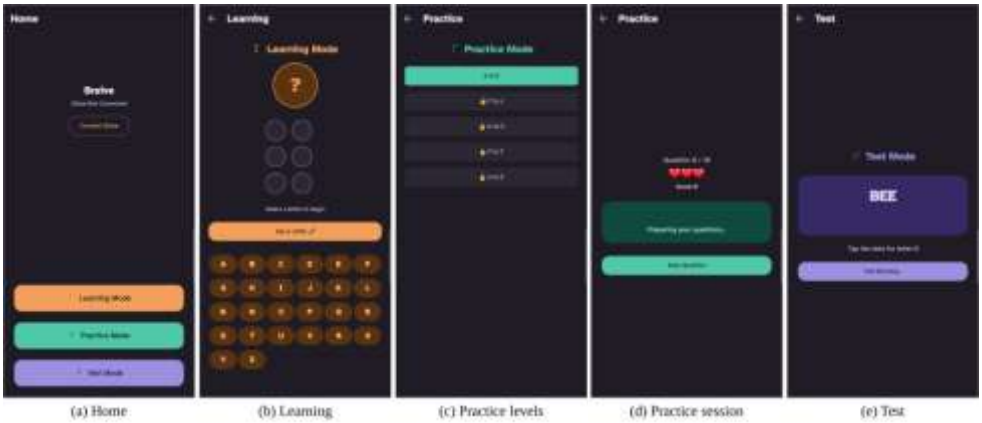


Fig. 2 Braive application screens: (a) Home, (b) Learning Mode, (c) Practice Mode level selection, (d) Practice session, (e) Test Mode.

D. *Discussion and Limitations*

The results demonstrate the integration of a vibrating glove, BLE communication, a speech interface and adaptive practice in a single offline learning system. Compared with slate-and-stylus teaching or touchscreen-only applications, Braive gives the child a physical sensation of each letter, lets the child answer by voice or by touch, and works without a teacher or a network. The adaptive generator spends practice time on the letters a child finds hard while keeping earlier levels fresh, and the account-free design keeps all data on the device. The main engineering lessons were queuing every GATT operation, assembling multi-dot answers over time, and handling the way letters are transcribed by speech recognition; each of these problems appeared only on real hardware.

The evaluation is functional and small-scale. BLE latency, speech-recognition accuracy, battery life and the other timing targets set as design requirements (for example 200 ms for a BLE write and 500 ms for audio feedback) were not measured, so these figures remain requirements rather than results. Testing used a single phone model, and no structured study with visually impaired children has been reported, so the learning benefit of the system is not yet demonstrated. No

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bill of materials was costed, so the low-cost claim rests on the use of commodity parts. The system covers only the 26 letters of Grade-1 Braille, the battery indicator is a low/OK flag, and the firmware uses blocking delays for vibration timing.

V. CONCLUSION

This paper presented Braive, an IoT-based Braille learning system that combines an ESP32-based vibrating glove with an Android application to teach Grade-1 English Braille through touch, sound and repetition. The glove provides six vibration motors and six tap switches, and the application connects over BLE to provide Learning, Practice and Test modes, with speech recognition, text-to-speech feedback, adaptive gamified practice and on-device storage, all offline. The ten unit-level tests passed and the glove and application worked together on a physical phone, but latency, accuracy and learning outcomes remain to be measured. Future work includes measuring BLE latency and recognition accuracy, a study with visually impaired learners, a true battery percentage using a voltage divider, non-blocking vibration timing, Grade-2 contractions, and a teacher or parent summary of per-letter accuracy.

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