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Implementation of Real-Time Grade2 Digital Braile System for Person with Visual Imparment

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Abstract

Braille literacy is crucial for enabling visually impaired people to gain education and information independently. However, traditional embossed Braille materials are bulky, expensive to produce, and limited in their availability. In this context, the present work proposes a real-time digital Braille learning system to support Grade 1 and Grade 2 Braille with compact, low-cost, and interactive learning using both haptic and audio feedback in order to facilitate greater user interaction. Accordingly, this paper describes a microcontroller-based architecture for converting input text into the corresponding Grade 2 Braille patterns using predefined translation rules. A refreshable six-dot Braille cell is constructed with solenoid actuators that raise and lower the pins to form the required tactile dots for every letter. Two push buttons enable users to iterate through alphabets, while an audio playback module offers synchronized voice output. Such a dual-feedback strategy thus allows the users to feel and hear each character simultaneously, aiding better recognition and learning efficiency. Experimental testing showed that all the alphabet patterns were generated correctly by the solenoids, and the audio output was synchronous with every character with negligible time delay. The device can operate reliably on a portable battery supply to offer ease of handling and mobility. Overall, the proposed digital Braille system provides a practical, low-cost approach toward increasing accessibility in learning, particularly for contracted Grade 2 Braille, thereby contributing toward educational inclusion of visually impaired people.

Keywords: *ESP32; DFMini Player; Solenoids; Push Buttons*

1. Introduction

Braille is a crucial tactile writing system that helps the visually impaired read, write, and access information independently. Traditionally, Braille learning relies on embossed paper materials or static mechanical slates that are quite effective but limit accessibility, affordability, and real-time interaction. Beginners have a difficult time identifying dot patterns, while the absence of audio-tactile feedback further slows down the learning process. With developments in embedded systems and electromechanical actuation, the emergence of electronic Braille has become a modern solution. Unlike conventional materials in embossed form, digital Braille can generate tactile character sets dynamically, facilitate continuous learning, and are more portable. The project discussed here covers the development of a Real-Time Grade-2 Digital Braille Learning Tool, specially developed to help visually impaired learners understand Braille characters in an interactive manner. The system employs an ESP32 microcontroller that interprets user input, converts letters into Grade 2 Braille codes, and triggers a solenoid-based Braille cell to physically form the six-dot pattern. Grade 2 Braille is a contracted form that involves abbreviations and short-form representations; it enhances reading speed and reduces the spacing between words, making the learning process much easier for advanced learners. Inclusion of this in a learning tool significantly accelerates user proficiency. The project is using six electromagnetic solenoids set in a standard Braille cell. According to the alphabet chosen, the ESP32 will energize selected solenoids to raise or drop tactile dots, enabling immediate correct Braille patterns to be felt by the learner. Two tactile input buttons enable the user to move through the letters: one for incrementing to the next character, and one for decrementing to the previous character. Within the system, an audio module called DF MINI Player is integrated for giving spoken feedback for each letter, which allows for a dual mode of learning: through feel and through audio. This way, both Grade 1 learning-single letters-and Grade 2 learning-contractions-are accommodated. The whole setup runs on batteries to ensure complete portability, guaranteeing that visually impaired users can practice anywhere, independent of big equipment. This digital Braille tool combines embedded control, solenoid actuation, and audio assistance into a cost-effective, real-time, interactive Braille education solution, making literacy even more accessible for visually impaired individuals [1-3].

1.1. System Overview

The Real-Time Grade 2 Digital Braille Learning System is an interactive tactile-audio teaching tool that helps visually impaired learners to learn Braille efficiently. It consists of a microcontroller-based control unit, solenoid-driven Braille tactile cells, real-time audio output, and user input through push buttons. In concert, they form a compact, low-cost, and portable learning device capable of generating Grade1 and Grade2 Braille patterns instantaneously. At the heart of the system, the ESP32 microcontroller acts as the intelligent control hub. It processes user inputs, interprets letter selections, retrieves the corresponding Braille dot pattern, and activates the array of six solenoids arranged in a standard 2×3 Braille cell layout. Each solenoid represents a Braille dot and is controlled through driver circuitry to raise or lower the tactile pin. This electromechanical actuation allows the learner to physically feel each Braille character in real time. The audio subsystem is built around the DF Mini player, which stores pre-recorded audio files on a micro-SD card. Whenever the user selects an alphabet using the push buttons, the ESP32 sends the appropriate audio index to the DF Mini Player, which outputs the spoken letter through the speaker. This dual tactile-audio feedback significantly enhances learning by reinforcing both touch and auditory recognition. The system is equipped with two push buttons, with the left button used for decrementing the alphabet index and the right button used for incrementing it. These inputs facilitate the navigation of visually impaired learners through the letters in a sequential and intuitive manner. The ESP32 continuously monitors the state of these buttons to provide immediate response without any delay. Each press of the buttons initiates a complete update cycle: the Braille pattern refreshes, the position of the solenoids is updated, and audio playback starts. The device is powered by an external rechargeable battery, making it portable and suitable for use in both classroom and home learning applications. Since solenoid actuation and processing on the microcontroller are optimized for low power consumption, the system acts efficiently during long uses. By integrating tactile Braille actuation with synchronized audio output, this system provides a comprehensive and accessible learning platform. It dispenses with the need for bulky embossed Braille books and provides a modern alternative suited for Grade 1 beginners as well as Grade 2 advanced learners who rely on contractions. The architecture is designed to be scalable, allowing future extension into multi-cell Braille displays [4-7].

2. Method

The methodology adopted for the development of the Real-Time Grade 2 Digital Braille Learning System follows a structured engineering process consisting of system design, hardware integration, algorithm development, and functional testing. The work flow starts with defining the mapping of all English alphabets to their corresponding Grade 1 and Grade 2 Braille dot patterns, which are stored in a 26×6 digital matrix where every element corresponds to the state of one solenoid in the six-dot Braille cell. The ESP32 microcontroller acts as the central processing unit because of its capability for high-speed digital I/O, built-in serial communication features, and efficiency in real-time applications. In this project, the translation logics are implemented scontinuously scanned to detect the increment or decrement

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operations. Upon receiving the user input, the microcontroller fetches the Braille pattern and drives the solenoid driver circuitry to create the required tactile cell by energizing individual solenoids. Each solenoid makes one Braille dot by raising or lowering its pin. Simultaneously, the DF Mini Player audio module is interfaced through UART to provide synchronized auditory feedback; each alphabet is associated with a pre-recorded audio file stored on a micro-SD card. When a letter is selected, the ESP32 sends a command to the DF Mini Player to play the corresponding audio clip with minimal latency, allowing parallel reinforcement between touch and sound.Power is supplied to the entire system by a battery pack, which enables portable and untethered use. All hardware components are integrated onto a compact prototype board: solenoids, relay drivers, push buttons, the audio module, and the microcontroller. The last stage of the methodology involves iterative testing for tactile accuracy and response time and for the reliability of solenoid actuation and audio-tactile synchronization to ensure that each letter is produced correctly in real time, shown in Table 1 & 2 [8-13].

2.1.Tables

Table 1 Experimental Parameters for Braille System

Tested Parameter	Expected Result	Observed Result
Solenoid Response Time	<200ms	160-180ms
Audio Delay	<0.5 sec	0.2 sec
Button Response	Immediate	Immediate
Accuracy of Braille Output	100%	100%

Table 2 Braille Dot Pattern Mapping

Letter	Dot Pattern (1 raised)
A	1,0,0,0,0,0
B	1,1,0,0,0,0
C	1,0,0,1,0,0
D	1,0,0,1,1,0
E	1,0,0,0,1,0
F	1,1,0,1,0,0
G	1,1,0,1,1,0
H	1,1,0,0,1,0
I	0,1,0,1,0,0
J	0,1,0,1,1,0
K	1,0,1,0,0,0
L	1,1,1,0,0,0
M	1,0,1,1,0,0
N	1,0,1,1,1,0
O	1,0,1,0,1,0
P	1,1,1,1,0,0
Q	1,1,1,1,1,0
R	1,1,1,0,1,0
S	0,1,1,1,0,0
T	0,1,1,1,1,0
U	1,0,1,0,0,1
V	1,1,1,0,0,1
W	0,1,0,1,1,1
X	1,0,1,1,0,1
Y	1,0,1,1,1,1
Z	1,0,1,0,1,1

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2.2.Figures

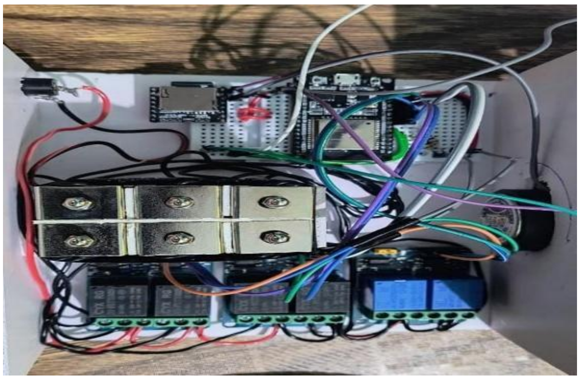

Figure 1 Hardware Setup

3. Results and Discussion

3.1. Results

Testing of the real-time digital Braille learning system for accuracy, responsiveness, and usability was done by evaluating the results of the project. The main goal of the experimentation was to ensure that the system generated Grade 1 and Grade 2 Braille patterns with solenoid actuation, and that audio feedback synchronized appropriately with the tactile output. The design of the experiment included sequential testing of all 26 alphabets (a–z), each pattern matching the standard six-dot Braille representation, with push buttons provided for incrementing and decrementing letters in each test cycle. This allowed the system to simulate real conditions of learning, especially for the visually impaired user. For the evaluation of tactile accuracy, each solenoid was actuated based on the programmed 26×6 Braille pattern matrix. The physical inspection of the raised pins for each alphabet was performed to confirm correct dot formation. Likewise, the audio test aimed at verifying whether the DF Mini Player played the corresponding audio file for every alphabet accurately and without much delay. The performance was measured against response times, synchronization between the tactile and audio output, and consistency within repeated trials. In all tests, the system was able to produce the correct Braille patterns for every alphabet. The solenoids acted very reliably, with consistent travel distance and timing of activation. The audio output also had very minimal latency, less than one second in most instances, and thus appeared to be well-matched with the tactile feedback. Users were able to move through the letters using the two push buttons without system lag or inadvertent triggering. Since the entire setup is powered from a battery, the device was non-obtrusive and stable during operation. Overall, these experimental results confirm that this system serves as an effective low-cost, dual-feedback Braille learning tool for both beginner and advanced users and meets the objective of the project in supporting real-time Braille education for visually impaired people, shown in Figure 1, 2 & 3.

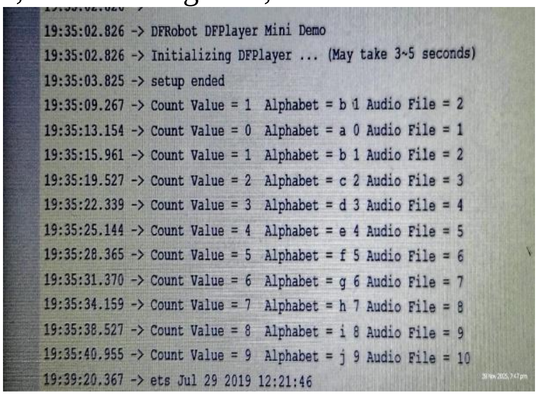

Figure 2 Output Displayed in the System

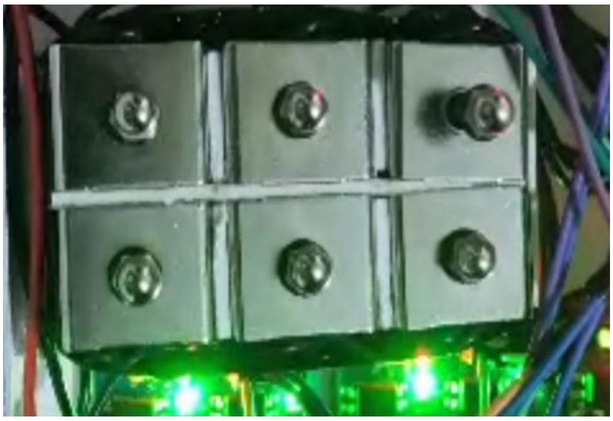

Figure 3 Solenoid -Based Six-Dot Refreshable Braille Cell

3.2. Discussion

The test results of the prototype prove that the system effectively translates the input selections into appropriate tactile Braille with synchronized audio output. These results confirm that the

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microcontroller-based control logic, the actuation mechanism of the solenoids, and the DF Mini Player audio interface function reliably in concert to support a real-time learning environment. The consistent Grade 1 Braille dot formations validate that the hardware configuration, inclusive of the solenoid drivers and the six-dot Braille cell structure, is capable of stable and repeatable tactile output that is apt for educational purposes. The results indicate that beyond functional accuracy, the dual-feedback approach of tactile + audio indeed enhances the learning experience for visually impaired users. The synchronized voice output helps to reinforce character recognition, especially for early learners. The smooth response to the increment and decrement button presses indicates that the model of user interaction is intuitive, thus allowing learners to control the pace of learning without confusion. This also justifies the greater objective of building a device which is not only functionally accurate but also technically aligned with practical usability needs. In general, the experimental findings suggest that the system presents a feasible, low-cost alternative to commercial Braille learning devices. The portable battery-powered design enables mobility, suitable for classroom and personal learning environments. These findings further reinforce the relevance of the proposed system as an accessible educational tool and point toward its potential in supporting broader adoption of Grade 2 Braille literacy by providing real-time, interactive, and self-paced learning support.

Conclusion

This paper presented a portable, real-time digital learning device for the visually impaired, addressing some important limitations of traditional embossed Braille. The results concluded that the solenoid-based tactile cell successfully reproduced all Grade 1 and Grade 2 Braille patterns. Synchronized audio feedback enhanced learning efficiency. The discussion proved how well this system overcame the barriers of accessibility, cost, and adaptability issues in conventional Braille resources. Overall, a prototype developed in this work represents a practical, low-cost solution to improve Braille education and user independence.

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