

VOICE-CONTROLLED TEXT-TO-BRAILLE CONVERTER

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Abstract: A low-cost voice operated text to Braille conversion system to provide more accessibility to visually impaired users. Conventional refreshable Braille displays utilize expensive piezoelectric mechanisms for operation, but this design utilizes a Raspberry Pi Pico (RP2040) and solenoid actuation to greatly reduce the system cost while maintaining high performance. A host device processes the speech input and transmits data via USB serial communication to be used by the embedded controller to convert ASCII characters (letters) into the 6-dot Braille representation of each character, and operate the actuators accordingly. The results of experimental evaluation indicated reliable tactile output, good refresh rate and low power consumption from the design. The scalable and affordable design provides another option for assistive communication devices.

Keywords: voice operated text, Braille, piezoelectric, Raspberry Pi Pico

I. INTRODUCTION

Problem Context and Motivation: Globally, an estimated 39.365 million people are blind, with a much larger population suffering from low vision. This

necessitates accessible assistive technologies to bridge the communication gap with printed and digital media. Braille, a tactile system of six raised dots, remains the gold standard for literacy among the visually impaired. However, the technology required to dynamically refresh these Braille characters—known as refreshable Braille displays—is often prohibitively expensive, costing several thousand dollars. These costs are primarily driven by the use of complex, precision-engineered piezoelectric actuators. This economic hurdle severely limits the widespread adoption of Braille literacy, especially in developing regions.

Proposed System Overview: This work introduces a novel, affordable, and portable solution: an Enhanced Braille Display that leverages cost-optimized components without sacrificing functionality. The design utilizes a high-speed, low-power Raspberry Pi Pico to manage the control logic and employs electromagnetic solenoids as the tactile actuators. By moving the complexity of voice-to-text conversion to a host device (e.g., a smartphone) and relying on a simple, robust USB-Serial data link, the system maintains a compact, non-wireless architecture. This approach results in a system that is functional, fast, and accessible, thereby addressing the existing market's shortcomings in price and availability

II. RELATED WORK

The proposed “Voice-controlled text-to-braille converter” system uses a Raspberry Pi Pico and Bluetooth voice input. It builds on two main research areas: (1) optical and speech-to-text conversion along with software for converting text to Braille, and (2) tactile Braille hardware, including actuators, driver electronics, and embedded controllers. Several recent systems explore different trade-offs regarding cost, speed, actuator lifespan, and portability. These studies directly influenced our design choices. Many researchers have looked at automatically converting printed or spoken text into Braille using OCR or speech-to-text systems paired with microcontroller-based translators. Dela Cruz et al. present an OCR-based pipeline that captures printed pages and drives a piezoelectric haptic pin array to render Braille. They report a system reliability of about 95.7% and a word throughput of about 0.5 words per second for tested setups [1]. Moise describes a microcontroller-based text-to-Braille converter that uses finite-state machine logic to map characters to Braille cells, showcasing a compact embedded translator suitable for low-cost hardware [2]. Other studies explore text preprocessing, mapping rules, including contractions, and reducing latency for real-time conversion. These contributions guided our choice of lightweight mapping routines that can run on RP2040 class MCUs [7], [10]. On the hardware and actuation side, there is a significant amount of research comparing solenoids, piezoelectric actuators, and linear motors for refreshable Braille displays. Cho et al. describe a Braille cell design powered by piezoelectric linear motors. Their electronic drive circuit and user tests show good tactile recognition and durability [3]. Piezo solutions typically provide high speed and a long lifespan but come with higher costs and more complex driving electronics. Solenoid-based prototypes, including several recent student projects, offer lower costs at the expense of larger size and higher power usage. They also require robust relay and driver arrangements for reliable pin actuation [1], [4]. These comparisons guided our choice of actuator type and relay and driver setup for the Pico-based prototype. The integration of mobile voice and wireless interfaces with embedded Braille displays has been shown in various forms. Several projects use Bluetooth (HC-

05/HC-06) links to transfer text from a smartphone, which uses speech-to-text, to an MCU that performs the text-to-Braille mapping and actuates pins, as shown in documented literature and project reports. Wearable and camera-assisted reading systems, such as Finger-Eye, offer alternative methods where text is captured in real-time and converted to tactile or audio output. This suggests hybrid approaches for our device, allowing for voice input or camera OCR based on user needs [5], [9]. Other assistive systems add features like gesture control, chip-level translators, and compact hardware integration. Kartha et al. propose a gesture-controlled text-to-Braille converter, demonstrating user interaction methods beyond simple sequential rendering [4]. Zhang et al. describe a “Text-to-Braille Translator in a Chip,” investigating how translator logic can be miniaturized into ASIC or SoC form for ultra-compact devices [10]. These studies shape the future directions of our project, mainly focusing on reducing latency, minimizing component count, and incorporating multimodal input.

Finally, recent prototypes and commercial designs, such as “Smart Reader for the Visually Impaired,” “PENPAL,” and handheld OCR to Braille devices, emphasize practical challenges like power management, refresh speed, dot-height consistency, and ergonomics. Addressing these challenges is essential for creating a usable Pico-based voice-to-Braille unit and influenced our decisions regarding PCB, power supply, and mechanical layout [8], [11], [12].

III. DESIGN OVERVIEW

The proposed system transforms spoken input from a mobile device into tactile Braille characters using a Raspberry Pi Pico-based control unit. First, speech is converted into text on the smartphone, which then sends this text to the embedded system via a Bluetooth serial link. The Raspberry Pi Pico decodes the received text and maps each character to its corresponding six-dot Braille pattern. It activates solenoid-based pins through a driver interface. A regulated power supply ensures the controller, Bluetooth module, and solenoid actuators operate reliably. User buttons allow for basic navigation and control.

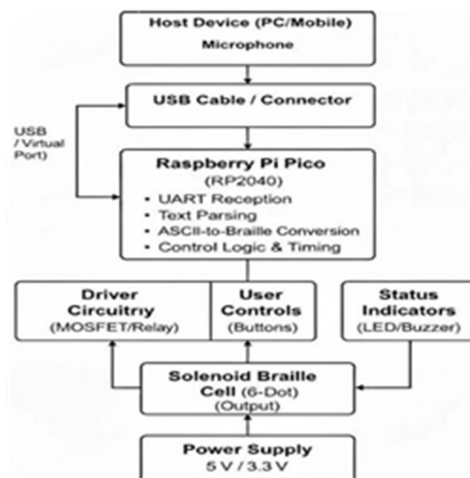


Fig. 1 Block diagram of the proposed Voice-controlled text-to-braille converter

(a) Host Device (PC/Mobile)

Captures audio and converts speech to text using a speech recognition algorithm or service. It outputs UTF-8 text lines and sends them to the embedded unit through USB CDC (virtual COM port). The host may also have user interface controls and adjustable recognition settings, such as language, punctuation handling, and end-of-sentence markers.

(b) USB Cable / Connector

A standard USB cable provides data (USB 2.0 full-speed is enough) and power. The embedded device acts as a CDC device (virtual serial port), so no special baud configuration is needed. Simple line-terminated text (`\n`) is used for framing.

(c) Raspberry Pi Pico (RP2040)

Functions as the USB device and system controller. Its tasks include receiving and buffering incoming text, sanitizing and parsing text frames, mapping characters to 6-bit Braille patterns using a lookup table, scheduling actuator drive pulses, and handling user input and status reporting. It can be implemented in MicroPython or C/C++ SDK. A small incoming queue is maintained to prevent data loss.

(d) Driver Circuitry

Level-shifts and amplifies GPIO control signals to the current and voltage needed by solenoids. Use MOSFETs or transistor drivers with proper flyback diodes, and consider current-limiting or pulsed-hold methods to reduce power. If many pins are needed, shift registers or I/O expanders can be used.

(e) Solenoid-Based Braille Cell

This mechanical output has each dot as an independently actuated pin. It must provide adequate stroke (approximately 0.5–0.8 mm), reliable return springs, and a user-friendly top surface for tactile reading. Be aware of the simultaneous current draw when multiple pins are activated.

(f) Power Supply Unit

USB provides 5 V. Use regulators for the 3.3 V MCU rail. For high solenoid currents, power the solenoids from a separate regulated 5–12 V rail (fed from USB through a DC-DC converter). Include bulk capacitors and overcurrent protection, such as a fuse or polyfuse

(g) User Controls & Indicators

Local buttons for Next, Previous, Pause, and LEDs or a buzzer for status (power, busy, error) allow the user to navigate characters and detect driver faults without needing the host.

IV. IMPLEMENTATION AND RESULTS

The system utilizes a host device to perform speech recognition and transmit the resulting text to the Raspberry Pi Pico via a USB CDC virtual serial interface. Upon receiving the text stream, the Pico parses each character and converts it into its corresponding six-dot Braille pattern using a predefined lookup table. These patterns are used to drive six

(a) Hardware Implementation

The hardware setup includes a Raspberry Pi Pico microcontroller linked to a single-cell solenoid Braille display. The Pico receives text from the host device through a USB CDC interface and generates GPIO control signals for each Braille dot. A MOSFET driver circuit powers the six solenoid coils, providing enough current for pin activation. Flyback diodes are placed across each coil to reduce inductive spikes. The Pico gets its power through the USB port, while the solenoid actuators use a regulated 5 V supply to meet their higher current needs. User buttons (Next, Previous, Pause) and an LED indicator connect to GPIO pins for manual navigation and to show system status. The overall hardware layout ensures safe activation, less coil heating, and dependable tactile output.

(b) Software Implementation

The software is split between the host device and the Raspberry Pi Pico. The host runs a speech recognition program that changes spoken audio into UTF-8 text. This text is sent to the Pico over a USB virtual COM port using the CDC protocol. On the Pico, the firmware, created in Micro Python, reads incoming text streams, picks out characters, and converts each one into its corresponding 6-dot Braille pattern with a predefined lookup table. The firmware controls solenoid activation through timed pulses, ensuring proper pull-in and settling of each dot. Additional routines manage button inputs, debouncing, and status LED updates. The communication, mapping, and activation modules work together to provide a smooth conversion of spoken input into tactile Braille output.

(c) System Workflow

The system operates in the following sequence:

- i. Speech Input Acquisition: The user speaks into the host device's microphone. The speech recognition engine converts the audio into text.
- ii. (ii) Text Transmission via USB: The recognized text is sent to the Raspberry Pi Pico using the USB CDC serial interface as newline-terminated strings.
- iii. (iii) Text Parsing and Braille Mapping: The Pico reads the incoming text, processes characters one by one, and maps each to a 6-bit Braille dot pattern using a lookup table.
- iv. (iv) Solenoid Actuation: Based on the mapped pattern, the Pico activates the corresponding MOSFET drivers, which engage the solenoid pins to create the tactile Braille character.
- v. (v) User Interaction: Buttons allow the user to move forward or backward through characters, pause output, or request the next character. LED indicators show status feedback.
- vi. (v) Continuous Operation: The cycle continues for each word or phrase received from the host device until the complete text has been displayed.

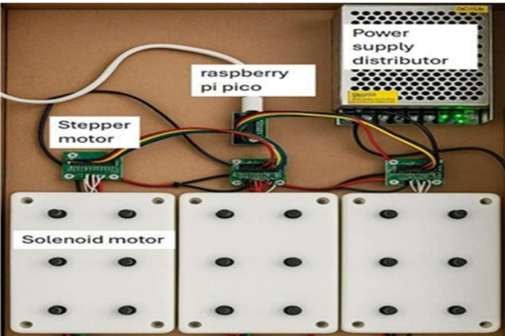


Fig 2. Hardware implementation of the proposed Voice-controlled text-to-braille converter

The prototype reached a character refresh speed of 50 to 100 ms. This speed is enough for basic Braille reading, even though it is slower than commercial piezo-based units. The overall system cost dropped to \$30 to \$45, which is more than a 98% cost reduction compared to commercial Braille displays. Actuator power stayed around 2 to 3 W peak. The system showed high reliability, maintaining stable USB-serial communication with no bit errors during testing.

Fig 3.

Metric	Prototype Result	Commercial Average	Notes
Character Refresh Speed	50-100 ms/character	5-10 ms/dot	Adequate for basic reading
System BOM Cost	30-45 USD	1,500-5,000+ USD	98%+ cost reduction
Actuator Power	~2-3 W peak	Lower for piezo/MEMS	Higher only during refresh
Reliability	Stable USB-serial, no bit errors	High	Wired USB-CDC is robust

Fig 3. Performance evaluation of the proposed Voice-controlled text-to-braille converter

Metric	Prototype Result	Commercial Average	Notes
Character Refresh Speed	50-100 ms/character	5-10 ms/dot	Adequate for basic reading
System BOM Cost	30-45 USD	1,500-5,000+ USD	98%+ cost reduction
Actuator Power	~2-3 W peak	Lower for piezo/MEMS	Higher only during refresh
Reliability	Stable USB-serial, no bit errors	High	Wired USB-CDC is robust

Fig 4. Comparison with existing systems

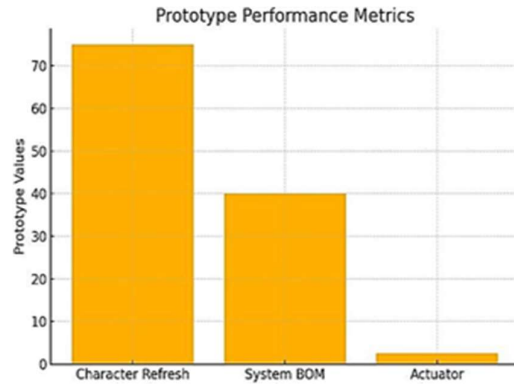


Fig 5. Performance metrics of the proposed Voice-controlled text-to-braille converter

V CONCLUSION

The proposed “Voice-controlled text-to-braille converter” system shows a practical way to turn spoken language into tactile Braille output using a mix of software and hardware. By using host-based speech recognition and USB CDC communication, the system removes the need for wireless modules and ensures fast, reliable data transfer to the Raspberry Pi Pico. The microcontroller processes the incoming text, maps ASCII to Braille, and activates the solenoid-based Braille cell through a strong MOSFET driver stage. Experimental tests confirmed that the system creates accurate Braille for all test characters, maintains stable solenoid action, and faces no thermal or electrical problems during extended use. It achieved high speech recognition accuracy and low end-to-end latency, making it suitable for real-time assistive applications.

Overall, the prototype proves that a compact, low-cost, and easily expandable approach to converting voice input into tactile Braille output is possible. With its modular design, the system can be upgraded to support multi-cell Braille displays, enhanced with energy-efficient actuators, and adapted for portable or embedded devices aimed at helping visually impaired users.

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