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Design of A Braille Printer Based on ESP32 Microcontroller with Voice Input

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ABSTRACT: Braille is a tactile phonetic alphabet system invented by Louis Braille, a blind teacher from France, in the 1800s. The Braille system was recognized as "a vital language of communication, as valid as all other languages in the world" in 2005. There are other alternatives, such as touch-based methods, to convey information that is generally obtained through sight. One of them is the use of Braille letters for reading, writing, and improving welfare by increasing insight. However, only 52 special schools in Indonesia have printers for Braille books. Limited access to Braille printing facilities in Indonesia is due to high costs. The cost of a printer machine, approximately 50 million per school, poses a challenge in providing learning facilities. This research proposes a compact and cost-effective Braille printer using an ESP32 microcontroller with both speech and mechanical switch inputs. The mechanical switch is used for typing text to be printed, while the microphone captures sound input in the form of audio, as it is easier to use. Audio input is processed using speech-to-text technology. The speech-to-text process is carried out with speech recognition, which listens to the words spoken by the user and matches them with the data in the module to execute specific commands. This Braille printer is designed to print Braille letters based on data received directly from individuals with and without disabilities. The printer accepts input in the form of speech or text, which is then sent to the processing module, the ESP32 microcontroller. Once all data is processed, the Braille printer module controls axis movements using a stepper motor. Braille prints are embossed to create raised dots on paper. Experimental results demonstrate 100% accuracy for both speech and typing inputs, along with reliable printing performance on standard HVS paper. Compared to previous solutions, the proposed design is more versatile, affordable, and portable. This study presents a practical solution for increasing access to Braille education and information.

KEYWORDS: Braille; printer; microphone; speech; ESP32

1. Introduction

Braille is a tactile phonetic alphabet system invented by Louis Braille, a blind teacher from France, in the 1800s [1]. He was inspired to create this reading system after becoming blind due to an injury. Around the same time, Charles Barbier worked to develop a raised-letter system for the military [2]. Braille refined Barbier's raised-letter concept, which remains in use today. UNESCO played a significant role in popularizing the Braille alphabet in 1950. In 2005, the Braille system was officially recognized as "a vital language of communication, as valid as all other languages in the world" [3]. However, Braille writing must be adapted to different languages to ensure accessibility and effective communication for people with visual impairments [4]. Examples of Braille letters in the alphabet system can be seen in Figure 1.

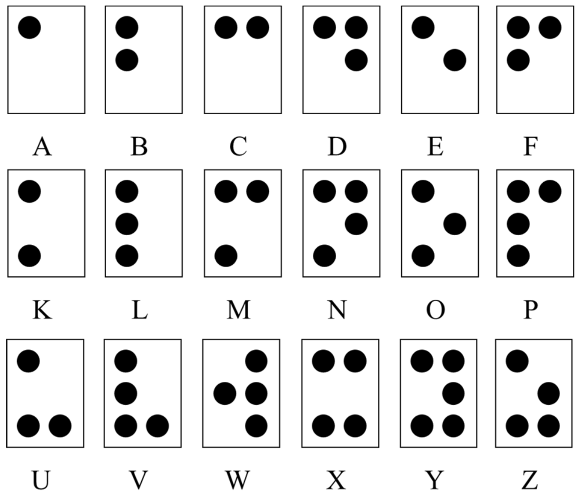


Figure 1. Example of Braille letters in English.

People with significant visual impairments must learn to read Braille to succeed academically [5]. They access written information by using their fingertips to read Braille letters [6]. Braille readers interpret text by moving their fingertips over raised Braille characters [7]. Research by Vandana [8] demonstrates that the learning time for school students is significantly reduced when using Braille. Braille readers obtain information by placing their fingers on raised Braille text, as shown in Figure 2.

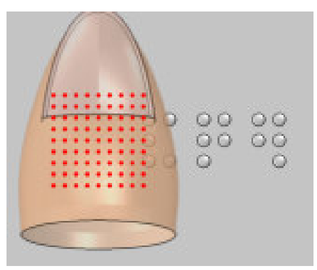


Figure 2. Braille reading [9].

Braille literacy is essential for individuals with visual impairments to access education and information. Despite its importance, access to Braille printing technology remains limited. In Indonesia, only 52 special schools have Braille printers [10], primarily due to the high cost of approximately 50 million IDR per printer. Braille printing must also be adapted to the linguistic rules of each language in use [11]. Many existing Braille printers rely on outdated technology and limited input methods, making them less adaptable to modern user needs [12]. The advent of microcontroller-based technologies and speech recognition systems offers new possibilities for developing cost-effective and efficient Braille printing solutions [13]. Innovations in digital speech processing and stepper motor control have enabled the creation of assistive devices that are more accessible and easier to use [14]. Integrating these technologies into Braille printers can provide a seamless experience for users unfamiliar with traditional typing methods. For example, speech input allows visually impaired individuals to communicate text naturally without requiring specialized training [15]. The size and portability of Braille printers are also significant factors [16]. Many existing Braille printers are bulky and designed for institutional use, making them unsuitable for personal or home applications. A more compact and lightweight Braille printer would greatly benefit students, professionals, and independent users who require quick and reliable access to printed Braille materials [17]. Addressing these design challenges can lead to broader adoption and accessibility of Braille printing technology [18].

Another crucial aspect of Braille printing is accuracy. The placement and spacing of Braille dots must be precise to ensure readability [19]. Modern stepper motors and solenoid-based embossing mechanisms provide an opportunity to enhance the precision and reliability of Braille printers [20]. By refining these components, it is possible to create a device that produces high-quality Braille output while maintaining low production costs [21]. This study explores the integration of modern technological advancements into Braille printing devices, focusing on affordability, user-friendliness, and adaptability. By incorporating voice input, mechanical switches, and real-time feedback mechanisms, the proposed Braille printer aims to bridge the gap between existing high-cost solutions and the needs of visually impaired individuals [22]. The findings from this research can contribute to the development of more accessible and inclusive assistive technologies in the future. Several studies and technological advancements have aimed to address these challenges. For instance, Küçükdermenci developed a unique Braille printer [23]. This printer design underwent various evaluations to enhance its performance. A Raspberry Pi-based Braille keyboard with an audio output can display Braille characters on an LCD screen and audibly announce them. The input module is a Braille keyboard. A key advantage of this product is its ability to display letters on an LCD for sighted companions. However, a limitation is that it only exists as a simulation in Proteus without a physical prototype.

Gurevin developed another Braille printer using electronic components [24]. This design incorporates an Arduino Mega and a six-pin unipolar stepper motor. The printer embosses Braille on aluminum paper and soft flooring materials. The input module is a software-based keyboard. The processing module relies on the Arduino Mega, while information is displayed through software and printed material. A key advantage of this device is that it successfully prototypes a Braille printer. However, its embossing force is too strong, making it unsuitable for printing on standard HVS paper. Arroyo et al. designed a low-cost printer head for embossing Braille using more cost-effective materials, making the product more accessible [25]. The printer head operates using a single servo motor that drives a hammer mechanism to emboss paper. The device employs a Braille Translator GUI application to convert text into Braille, with input provided via a standard keyboard. The processing module consists of a computer connected to the device, while output is displayed on printed paper. A major advantage of this system is its ease of use for printing Braille text via computer input. However, its limitation is that not all visually impaired users are familiar with computers. Despite this, the device facilitates book printing for other users. These restrictions highlight the need for specialized equipment to enhance accessibility in Braille printing. The proposed Braille printer integrates a microphone and mechanical switch for input. It utilizes an ESP32 microprocessor and an ESP32 shield for processing. Speech recognition v3 is employed for data processing. An LCD screen displays output, while a buzzer signals successful printing. The Braille printer embosses text using a solenoid mechanism. The LCD display ensures ease of use for all users.

A comparison of the proposed Braille printer with existing solutions is presented in Table 1, evaluating parameters such as input methods, processing units, information display mechanisms, and printing components.

Table 1 Designed Braille printer.

Parameter	**Serhat Küçükdermenci** [23]	**Gurevin** [24]	**Arroyo** [25]	**Braille Printer**
Input	microphone and laptop's keyboard	keyboard	keyboard	microphone and 7 mechanical switch
Processor	raspberry pi	arduino Mega	computer	micro-controller esp32
Information Display	not available	paper	computer's monitor	paper, LCD, and buzzer
Printing Components	not available	servo dan pulley belt	servo motor	solenoid

This study aimed to develop a compact, cost-effective Braille printer based on an ESP32 microcontroller, integrating both speech and mechanical switch inputs. By incorporating a speech recognition module, the proposed design allowed users to input text through voice commands, making the device more accessible to visually impaired individuals. The mechanical switch input followed the Perkins keyboard layout to ensure usability. The ESP32 microcontroller processed these inputs and controlled the movement of a stepper motor and a solenoid-based embossing mechanism to create Braille dots on standard HVS paper. The system also included an OLED display and a buzzer for real-time feedback. The Braille printer sought to address the current limitations of high-cost and outdated designs by offering a more affordable, user-friendly, and portable alternative. By providing an inclusive and accessible printing solution, this research contributed to improving literacy and educational opportunities for visually impaired individuals, particularly in underserved regions. The findings from this study demonstrated the feasibility of integrating modern microcontroller and speech recognition technologies into assistive devices, paving the way for further advancements in Braille printing solutions.

2. Materials and Methods

2.1. Materials.

The design of the Braille printer with a microphone and keyboard consisted of several components. These components included the DFrobot Speech Recognition module, mechanical switches, an ESP32 microcontroller, an SSH1306 OLED, a DRV8825 stepper driver, a NEMA 17 stepper motor, a relay, and a solenoid.

2.2. Methods.

The working mechanism of this system was illustrated in a block diagram. The block diagram showed the connection among the components of the Braille printer to execute the command for printing Braille letters. The system's block diagram consisted of several modules, including the speech module, typing module, processing module, information display module, and printing module. Figure 3 presents the block diagram.

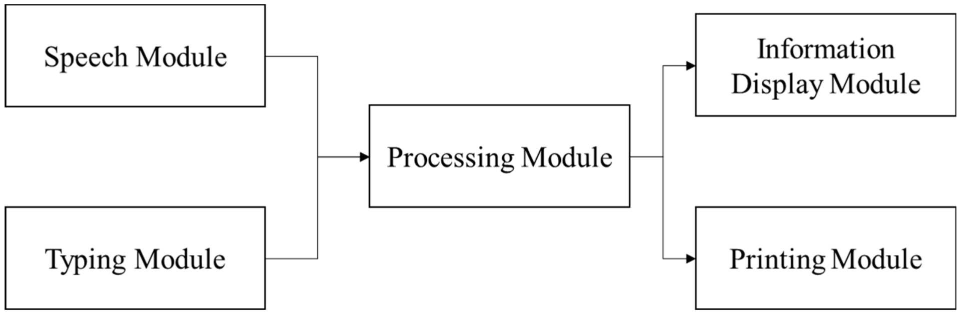


Figure 3. Diagram block system.

The proposed design was a Braille printer capable of printing Braille letters on paper. Braille is a phonetic alphabet system used by individuals with significant visual impairments. The Braille printer was equipped with a microphone to record audio. First, the user's audio was received by the speech module. This module's hardware included a microphone to capture the user's voice. The user's speech served as the input when they pronounced words, letters, or sentences. Second, the typing module was used to type Braille letters as input. This module consisted of seven mechanical switches arranged based on their functions. The Braille printer's input was derived from the Perkins keyboard layout, which comprised six mechanical switches for dots and one mechanical switch for spacing, positioned according to Braille dots. The mechanical switch design was developed for user convenience and as a backup offline option, particularly for Braille-typing users. Third, the processing module handled data processing. The data fell into two categories: speech data and text data. Speech data was obtained from the speech module, while text data came from the typing module. The speech module converted speech to text using Speech Recognition v3. The speech-to-text conversion was performed in real-time, processing up to 50 words. The typing module transmitted information about the dot positions based on the pressed mechanical switches. The Braille dot information from the typing module was sent to the processing module, which then converted the text data or Braille dot positions into a readable format. Fourth, the information display module was responsible for displaying data information. This module included an OLED and a buzzer. The OLED displayed input received from the speech or typing modules, allowing verification that the input matched the Braille letters to be printed. The buzzer functioned as an indicator, signaling each time the printer processed a Braille letter. Fifth, the printing module printed Braille letters and consisted of a paper holder, paper, stepper motor circuits, and solenoids. The Braille printer utilized stepper motors to enable movement along the x, y, and z axes, allowing three-directional motion: up-down, left-right, and forward-backward. Solenoids acted as the printer head, creating raised Braille dots. The paper holder secured the paper within the printer. Standard HVS paper was used for printing to maintain the quality of the Braille letters.

2.2.1 Speech Module.

The speech module utilized the Dfrobot SKU_SEN0539, a module designed to receive sound input from a microphone. The sound captured by the microphone was processed into digital signals, which were then converted into text through a speech-to-text process using speech recognition algorithms. The process began with the input of multiple training words, repeated several times to allow the module to accurately record and learn sound patterns. Once the training process was complete, each speech command was assigned a unique command ID, which served as an identifier for subsequent processes. Figure 4 illustrates the implementation of the speech module.

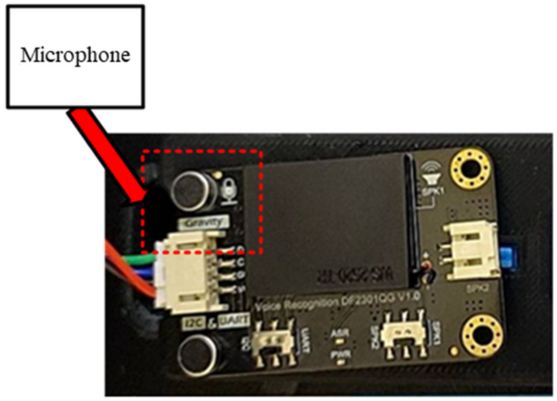


Figure 4. Microphone on the Dfrobot SKU_SEN0539 as the speech module.

2.2.2. Typing module.

The typing module functioned as the input medium in this design. It consisted of seven buttons arranged in a specific formation, commonly known as the Perkins Keyboard. By pressing the buttons, users could generate the desired Braille characters. The typing module is illustrated in Figure 5.

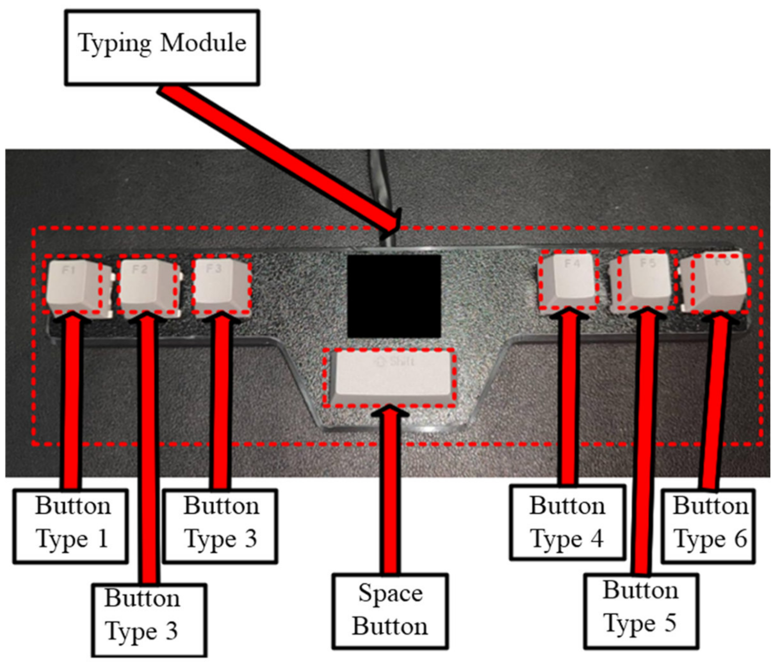


Figure 5. Configured mechanical switches based on the perkins keyboard as the typing module.

The typing module used mechanical switches that converted physical pressure on the buttons into electrical signals. When a button was pressed, the circuit was completed, and a signal was sent as a combination of button presses based on the button's position. For example, to type the letter "A," the user simply pressed the Dot 1 button, where the signal from this button was interpreted as the Braille pattern with a dot in the first position (Dot 1). For the letter

"B," the user had to press both the Dot 1 and Dot 2 buttons simultaneously, resulting in a Braille pattern with dots in the first (Dot 1) and second (Dot 2) positions. After completing the button combination for a character, the user pressed the Space button to initiate the printing process for the entered Braille character.

2.2.3. Processing module.

The processing module was designed using the ESP32 microcontroller. It handled the transformation from input to output and was programmed in C++ using the Arduino IDE. Figure 6 illustrates the processing module. The program in the processing module executed commands to initialize the use of GPIO on the module. This initialization was performed to enable the processing module to start converting input into output using the predefined GPIO.

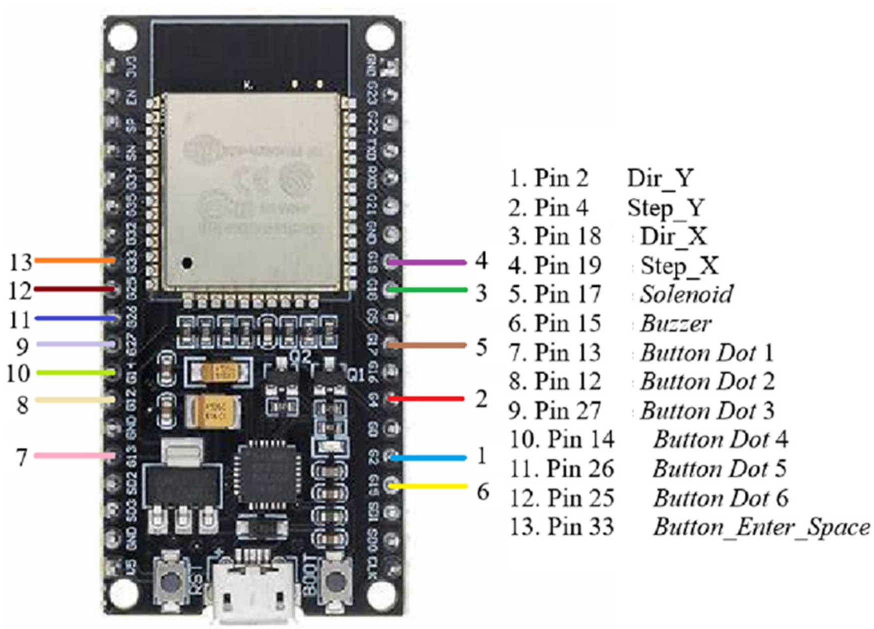


Figure 6. ESP32 as the processing module.

2.2.4. Display module.

The information display module consisted of a display screen and a buzzer. The display screen used a 0.96-inch OLED to display information such as the characters to be printed and the operating mode. The OLED screen was of the SSD1306 type and communicated via the I2C protocol. The information display module can be seen in Figure 7. The buzzer in the information display module functions as a notifier, emitting a "beep" sound when the device is active. The buzzer can be seen in Figure 8.

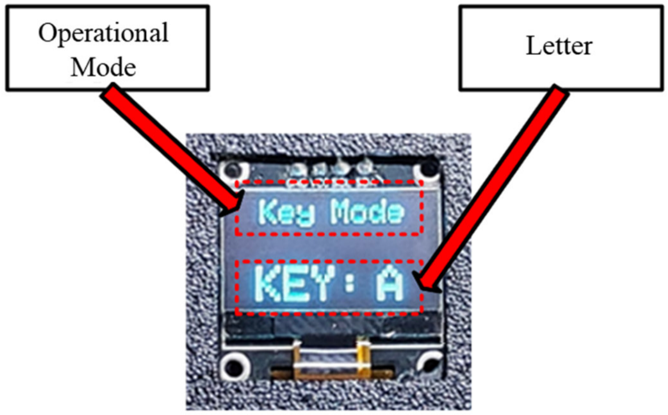


Figure 7. OLED for the display screen design.

Figure 8 Buzzer for the Display Module

2.2.5. Printing module.

The Braille printer module consisted of the actuator and the embosser. The actuator used two DRV882 drivers, NEMA 17 stepper motors, relays, and solenoids. The DRV882 driver controlled the NEMA 17 motors on two axes. These two axes functioned to move the paper forward or backward and to move the solenoid left or right. The actuator can be seen in Figure 9. The embosser in the printer module used a solenoid and relays. The solenoid functioned as the embosser, enabling the paper to display Braille dots. The relay controlled the solenoid's movement. Figure 10 shows the printer module.

Figure 9 Actuator design: (a) NEMA 17 stepper motor module.

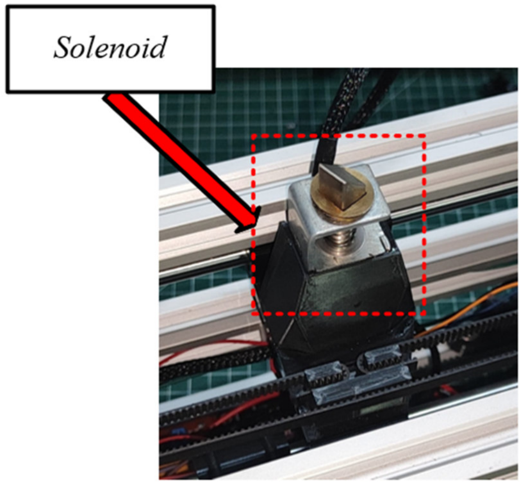


Figure 10. Printing head of the printing module.

2.2.6. Proposed Braille printer design.

The overall system implementation was carried out by integrating all the designed subsystems. The speech module was connected to the processing module via an I2C serial interface. The information display module and typing module were placed in the keyboard unit and connected to the processing module using data cables. The Braille printing module utilized stepper motors and solenoids, which were connected to the processing module through a stepper driver and relays. The complete system implementation can be seen in Figure 11.

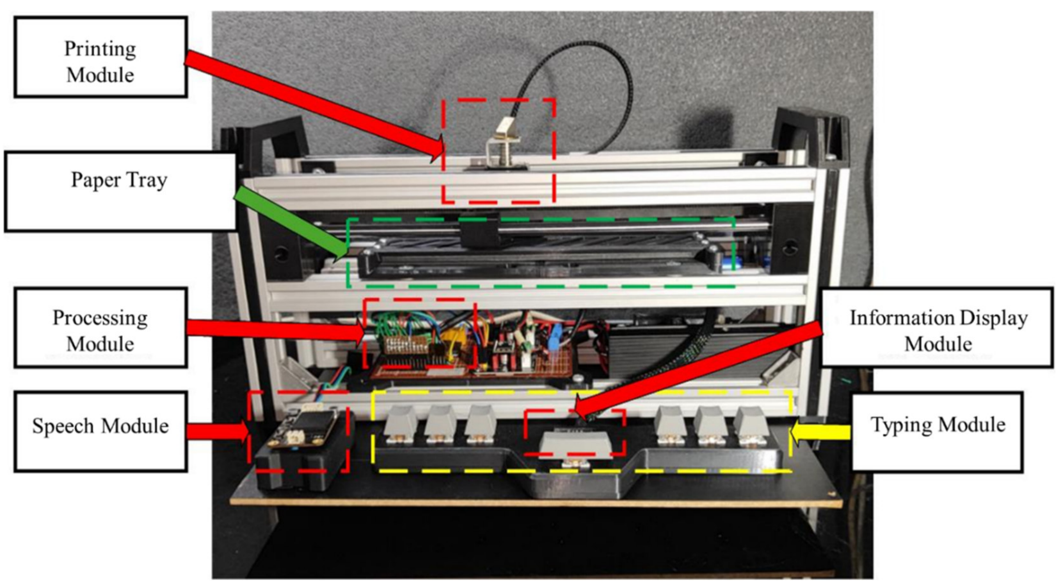
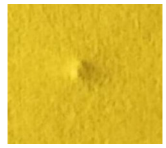
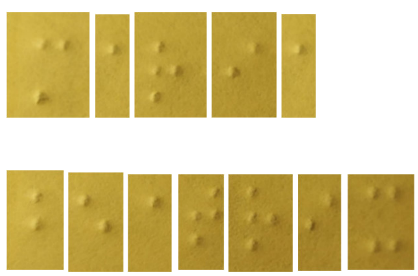


Figure 11. Our proposed Braille printer.

3. Results and Discussion

The testing was conducted to ensure that all modules functioned properly. Input was performed in two ways by selecting either the speech module or the typing module. The speech module used a microphone placed 5 cm away, while the typing module received input from mechanical switches. The processing module successfully processed information on the ESP32. The information display module operated the OLED correctly. When matching input was given, the buzzer sounded. Meanwhile, the printing module accurately printed Braille text. Every letter of the alphabet, from A to Z, was tested using both the speech and typing modules. The results of the overall system testing are presented in Table 2.

Table 2. Overall system testing by example of input.

Case Example	Display Modul Result	Printing Module Results	Explanation
Input A from speech module			
Input B from typing module			
Input from the speech module, letter by letter, for the word "Maria Beatrix"			

Case Example	Display Modul Result	Printing Module Results	Explanation
			

The Braille printer is able to print two simultaneously by this printer. The words can also be printed in two distinct rows on the Braille printer. Figure 12 shows printing in different rows.

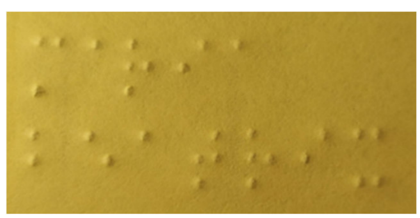


Figure 12. Two rows and multiple words.

Each module functioned accurately. The speech module correctly identified speech and converted it into text. The accuracy of the typing input was 100%. The processing module successfully processed the input without errors. The information display module accurately displayed the words and emitted a beep as expected. The printing module consistently printed Braille correctly. Compared to previous designs, the proposed printer demonstrated superior versatility by supporting both speech and mechanical switch inputs. The integration of an OLED display and a buzzer further enhanced user interaction. The data are presented in Table 3.

Table 3 Overall system testing by example of input.

Case Study	Accuracy	Description
Accuracy for speech module	100 %	Speech module is able to perfrom speech to text accurately
Accuracy for typing module	100%	Typing module is able to give type input accurately
Accuracy for processing module	100%	Processing module is able to process the data accurately
Accuracy for information display module	100%	Information display module is able to display the information accurately
Accuracy for printing module	100%	Printing module is able to print accurately

4. Conclusions

The conclusions drawn from the design of a Braille printer based on the ESP32 microcontroller with speech input are as follows. First, the speech module accurately recognized spoken words at a distance of 5 cm. Second, the typing module, using a Perkins keyboard, successfully arranged six Braille dots. Third, the ESP32 processing module effectively connected the speech module, typing module, information display module, and printing module. Fourth, the information display module displayed the typed letters and printer status, including operating modes. Fifth, the printing module successfully printed Braille letters on paper in a single-column pattern. Sixth, the entire system accurately recognized and printed letters from A to Z. Based on the results of the Braille printer design, several recommendations can be made. First, incorporating additional subsystems, such as a speaker, could provide auditory feedback. Second, further system development could enable the printing of Braille numbers and symbols. Third, reducing the device's weight would improve mobility.

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Author Contribution

Conceptualization, Data Analysis, and Writing: Maria Beatrix, Wahidin Wahab, Meirista Wulandari.

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