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AI-Powered Braille Learning and Assistance System for Visually Challenged Individuals

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Abstract: This project presents an AI-powered Braille Learning and Assistance System designed for visually challenged individuals, aiming to make education more inclusive and adaptive. The system integrates tactile Braille feedback using six servo motors and voice-based interaction via speech recognition and synthesis. It runs entirely on a Raspberry Pi 4, making it compact and deployable in low-resource environments. The use of lightweight large language models (LLMs) like Phi-3 and SmolLM2 allows real-time, locally processed conversational AI. This enables personalized teaching, content summarization, and interaction without requiring internet connectivity. The solution shows promise for educational settings where accessibility and adaptability are crucial.

Index Terms: Braille learning, visually impaired, Raspberry Pi, speech-to-text, AI assistant, offline system

I. INTRODUCTION

Inclusive education is a fundamental human right, yet many visually challenged individuals continue to face substantial barriers in accessing mainstream educational resources. While traditional tools such as screen readers and text-to-speech (TTS) systems provide some level of support, they often lack interactivity and adaptability, resulting in limited user engagement and reduced retention of learning material.

To address these challenges, this project presents a low-cost, AI-powered Braille Learning and Assistance System that leverages both tactile and auditory feedback to enhance accessibility and learning outcomes. Designed with affordability and scalability in mind, the system is built on a Raspberry Pi 4 platform and uses six micro servo motors to provide real-time conversion of spoken input into Braille patterns, allowing users to physically read through touch.

The system features speech recognition capabilities for hands-free operation, as well as text-to-speech synthesis to offer immediate auditory feedback. Furthermore, it integrates lightweight, offline-capable language models that enable AI-driven interaction without the need for constant internet connectivity. This makes the solution particularly suitable for deployment in rural or low-connectivity regions, where access to reliable digital infrastructure is often limited.

By combining tactile learning with intelligent auditory assistance, this project aims to create a more inclusive, engaging, and self-paced educational environment for visually challenged learners.

II. RELATED WORK

Many studies have attempted to improve Braille literacy and support for people with visual impairments. These initiatives demonstrate the continuous need for practical ways to enhance communication and learning in Braille. However, a lot of the current methods have drawbacks in terms of adaptability, accessibility, or functionality. For example, the spoken dialogue-based Braille teacher developed by Kyoto Institute [8] offered modular voice interface, enabling users to communicate with a system by speaking. Despite prioritizing auditory learning, this approach lacked tactile output, which is essential to Braille literacy. Although speech interaction has its uses, it lacks the tactile feedback necessary for users to become effective Braille readers.

The interactive Braille slate system [7] from Thinkerbell Labs combined cloud analytics and stylus input to provide a computerized and engaging method of learning and writing Braille.

For the purpose of tracking progress and customizing learning, this system made use of cloud connectivity to deliver statistics and feedback. Its reliance on proprietary technology, however, limited accessibility and adaptability, which may increase costs and reduce usability in places with limited resources. For customers without dependable internet access, the dependence on cloud connectivity presents additional difficulties. Mobile apps [9] and AI-assisted wearables [10] have also been studied; they include object detection and image recognition features to help visually impaired people navigate their environment. Users can read text in their surroundings and recognize things with the aid of these technologies.

Real-time Braille feedback, which is essential for direct Braille learning and communication, is typically absent from them. While mobile apps could not always offer a constant and reliable user experience, wearable technology may face issues with user comfort and societal acceptance due to bulkiness or stigma.

Our innovative approach focuses on offline multimodal interaction, integrating accessibility and versatility through local AI, speech synthesis, and tactile Braille output. This offline feature ensures self-directed learning, privacy protection, and improved comprehension, accommodating various learning methods and ensuring accessibility regardless of internet connectivity.

III. PROPOSED METHODOLOGY

By effectively combining tactile Braille output and synthesized speech feedback, the proposed approach provides educational support, specifically designed to empower visually challenged learners. The system's complete offline operation makes it ideal for rural, isolated, or under-connected areas where typical assistive technologies might not work because of reliance on continuous power sources or cloud infrastructure. The system's modular architecture permits components to be upgraded or swapped out as needed for future development, guaranteeing flexibility, maintainability, and scalability. The following essential modules make up the architecture:

Speech Recognition (gTTS): This module uses gTTS or pyttsx3, a small and incredibly accurate offline speech-to-text (STT) engine, to handle spoken input that is recorded via a USB microphone. Without the need for internet connectivity or cloud-based APIs, it effectively converts user commands and inquiries into text in real time, facilitating natural voice interaction.

SmolLM2, a 360-million-parameter local language model that can produce pertinent and context-aware answers to user inquiries, is the brains behind the system's intelligence. It is deployed on the Raspberry Pi using llama.cpp and guarantees that query comprehension, reasoning, and explanation are carried out entirely offline, preserving low latency and anonymity.

Text-to-voice Engine (pyttsx3): This part manages the synthesis of text to voice, translating AI-generated responses into audible output that sounds clear and natural. With its support for multilingual settings and customizable voice characteristics, learners can get spoken feedback that suits their preferred comprehension style.

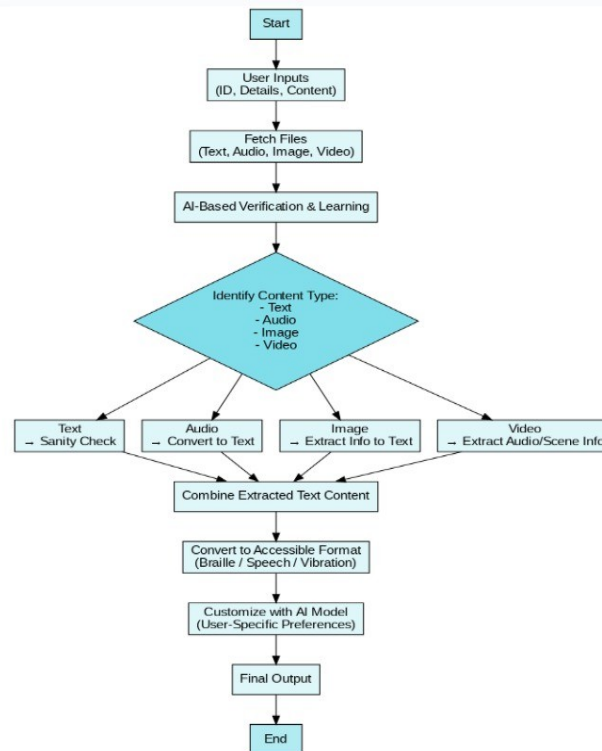


Fig.1. Block Diagram

6-Servo Braille Display: The system has a servo-driven Braille cell that replicates the conventional 6-dot Braille arrangement for tactile feedback. Every servomotor is controlled by Raspberry Pi GPIO pins and correlates to a distinct Braille dot. The learner's capacity to physically absorb and assimilate information is improved by this module's real-time, character-by-character Braille representation.

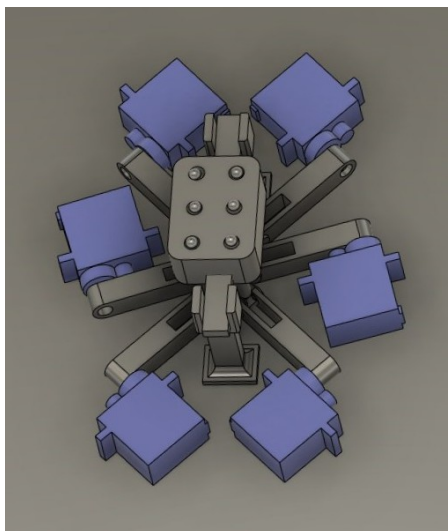


Fig.2.servodisplay

Customization and Voice-Based Note Taking: This feature lets user stake, organize, and store notes with just their voice. It also enables modification of system behavior, such as response style, Braille output delay, tone, and voice speed. Because these settings are locally kept, they provide a customized and flexible learning environment free from outside dependencies.

IV. HARDWARE AND SOFTWARE IMPLEMENTATION

The Raspberry Pi 4 Model B is a small, energy-efficient platform suitable for educational installations, especially in limited resources. Its compact size allows easy integration into portable or fixed installations. Vosk, an offline speech-to-text engine, ensures accurate and speedy transcription of voice commands, making it ideal for remote or rural areas without internet connectivity. Six servo motors set up in the typical Braille cell configuration make up the Braille output unit. These can convert any character into tactile form and are controlled by the Raspberry Pi's GPIO ports. Because the display speed can be changed by the user, it may be tailored to the reader's comfort level and familiarity.

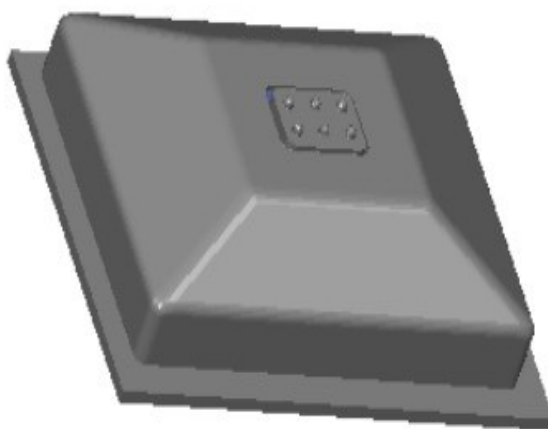


Fig.4. shows the CAD design of the Braille output device.

The results confirm the effectiveness of AI-powered multi-modal systems in improving access to education for visually impaired students. These systems combine intelligent answer generation, synchronous voice feedback, and tactile Braille output.

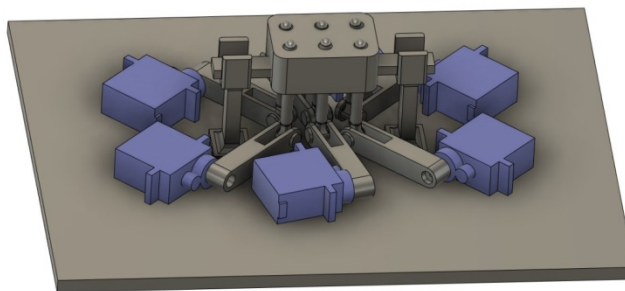


Fig.3.Hardwaresideview(open)

To process user queries, a 360 million parameter language model called smolLM2 is implemented into a local instance. This model enables real-time, context-aware conversational responses, and understands spoken inputs—all while remaining completely offline. It is appropriate for real-time operation on the Raspberry Pi due to its effectiveness and compact size. Pyttsx3, a flexible text-to-speech engine that supports a variety of languages and voice configurations, is used to deliver final outputs. It provides dual-mode feedback to improve comprehension and synchronizes with the Braille display. By providing users with both tactile and audible reinforcement, this multisensory delivery enhances accessibility and learning results.

V. RESULTS

The prototype was successfully tested on a Raspberry Pi 4B (4GB RAM) with a 128GB high-speed SD card. Benchmarks confirmed smooth real-time performance of servo actuation, voice recognition, and AI inference with no noticeable lag. Key features validated include:

- Reliable Braille output for all English alphabets
- Voice interaction with real-time transcription and storage
- Basic conversational AI capable of summarizing text and answering queries

User feedback from a visually impaired educator emphasized the usefulness of voice speed control and tactile output clarity. Challenges encountered included servo precision tuning and microphone noise, both of which were addressed during iteration.

VI. CONCLUSION

The development of this AI-powered Braille Learning and Assistance System demonstrates that accessible, adaptive learning tools for visually challenged users can be both affordable and practical. By leveraging servo-actuated Braille, voice interaction, and offline LLMs on a compact Raspberry Pi 4, the system offers a stand-alone solution for personalized education. Future improvements could include emotion-aware text-to-speech, multilingual support, and enhanced facial recognition to provide context-based feedback. This work lays the foundation for an inclusive educational assistant that can support children, adults, and the elderly, especially in underprivileged or remote areas without stable internet access.

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