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Review RTSRT

Brain- and Gesture-Controlled Assistive System for Physically Challenged Individuals

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Abstract

Assistive communication technologies are essential for improving the independence of individuals with physical and sensory disabilities. This paper presents the design and implementation of a multimodal assistive system that integrates brain signal acquisition and gesture recognition for real-time communication. The system utilizes an electroencephalography (EEG) sensor to capture neural activity and a PAJ7620 gesture sensor along with an ADXL335 accelerometer to detect hand movements. The acquired signals are processed using an Arduino Nano microcontroller, where predefined logic and threshold detection are applied to generate assistive commands. These commands are displayed on a 16×2 LCD and transmitted wirelessly using a 433 MHz RF module. A DF Mini MP3 module provides voice output for emergency communication. The system demonstrates an average response time below one second, gesture recognition accuracy above 90%, and reliable wireless communication up to 20 meters. The proposed system offers a low-cost, portable, and efficient solution for assistive communication. Designed for ease of use and requiring little training, the system is accessible to people with different levels of disability. Its modular design permits easy expansion with extra sensors or advanced AI-based processing to enhance accuracy and adaptability. By diminishing reliance on one communication method, the incorporation of multimodal inputs improves reliability. This strategy helps to boost users' confidence and feelings of safety, as well as their quality of life. It also offers a scalable framework for future developments in assistive technology.

Keywords: Assistive technology, brain–computer interface (BCI), electroencephalography (EEG), gesture recognition, Arduino Nano, embedded systems, RF communication, multimodal control

INTRODUCTION

Individuals with severe physical and sensory impairments often face difficulties communicating and interacting with their environment. Conventional assistive systems rely on physical input methods, such as switches or speech-based interfaces, which may not be suitable for users with multiple disabilities. Brain–computer interface (BCI) technology provides an alternative approach by enabling direct communication using brain signals [1, 2].

Research on assistive systems that can cater to various user requirements has gained momentum owing to the increasing need for inclusive technologies. The creation of compact and efficient communication devices designed for people with limited mobility has been made possible by advanced sensor integration and embedded systems. These systems are designed to connect user intention with external interactions, offering a communication experience that is more natural and seamless [3, 4].

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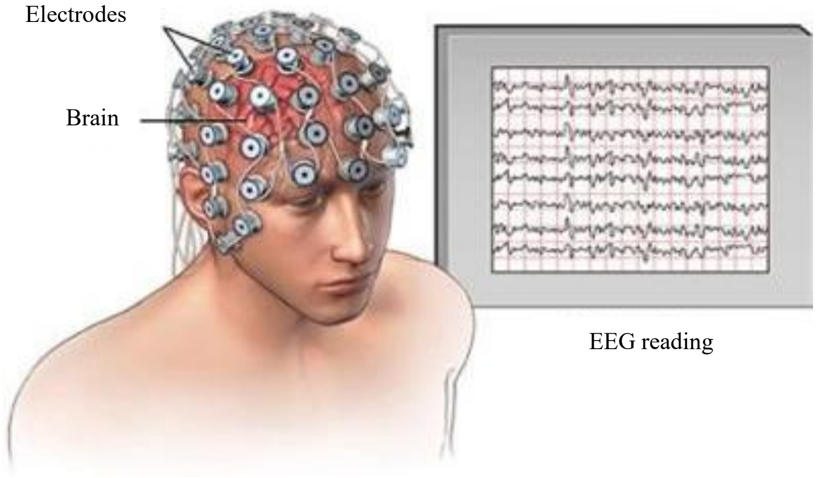

Figure 1. Electroencephalography (EEG).

Electroencephalography (EEG) based systems allow noninvasive acquisition of brain activity; however, they are often affected by noise and signal instability. Gesture-based systems provide an intuitive and contactless interaction method but are limited to users with restricted movement. Therefore, combining multiple input methods can improve the reliability and usability of the system [5, 6].

To address these challenges, effective signal conditioning methods such as filtering, amplification, and feature extraction are crucial for enhancing the quality of EEG signals. Likewise, the accuracy of gesture recognition can be improved by employing calibrated sensors and refined threshold algorithms. By integrating these modalities, redundancy is created, and one input method can offset the limitations of the other, thus enhancing system reliability [7, 8].

The proposed system includes an EEG sensor for capturing neural signals and gesture recognition sensors for detecting hand movements, all of which are processed through a microcontroller-based architecture. With the ability to show or transform into voice output, the system produces predefined commands that facilitate effective communication, even during emergencies [9, 10]. The experiments showed better response time, increased recognition accuracy, and consistent system performance across different conditions. Moreover, the system is designed to be portable, energy-efficient, and user-friendly, making it appropriate for practical use. By offering a dependable and smart means of communication, this strategy could enhance the quality of life of people with disabilities [11, 12].

This study proposes a multimodal assistive communication system that integrates EEG, as shown in Figure 1, and gesture-based control in a single embedded platform. The system aims to provide a flexible, low-cost, and real-time solution to enhance user independence [13].

SYSTEM ARCHITECTURE

The proposed system, as shown in Figure 2, consists of four main units: input acquisition, processing, output, and wireless communication. The input unit includes an EEG sensor, PAJ7620 gesture sensor, and ADXL335 accelerometer, which capture brain signals, hand gestures, and motion inputs.

The processing unit is based on an Arduino Nano microcontroller that analyzes the signals using threshold detection and predefined logic. An input selection switch allows operation in either the EEG or gesture mode.

The output unit includes a 16×2 LCD and a DF Mini MP3 module for visual and audio feedback. The wireless communication unit uses a 433 MHz RF module to transmit signals to the caregiver, where a buzzer is activated, as shown in Figure 3.

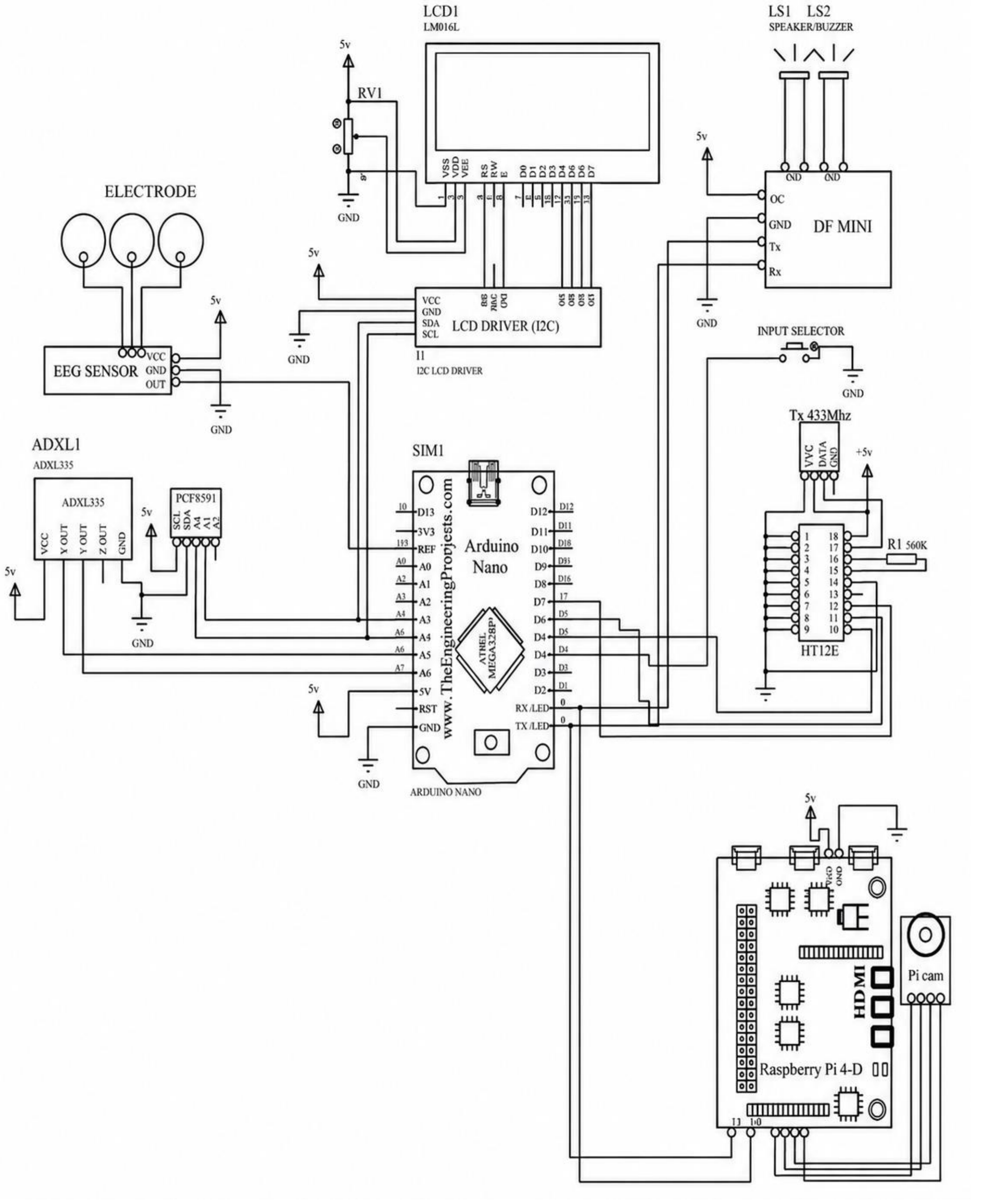

Figure 2. Layout of proposed system.

A regulated power supply ensured stable system operation. The architecture supports real-time processing and allows for future expansion.

PROPOSED SYSTEM

The proposed system is a multimodal assistive communication platform that integrates EEG-based brain signal control and gesture recognition into a single, embedded system. The system is designed to assist physically challenged individuals by providing an alternative method of communication and interaction.

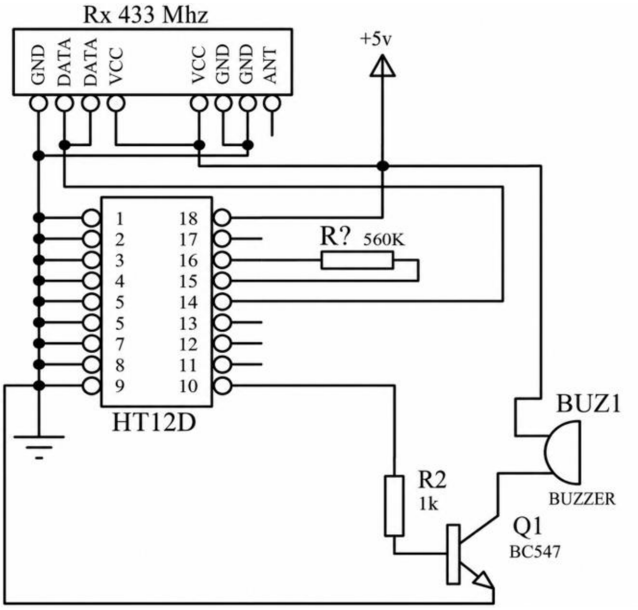

Figure 3. Layout of caretaker side.

The system utilizes an EEG sensor to capture brain signals and a PAJ7620 gesture sensor with an ADXL335 accelerometer to detect hand gestures and motion. These inputs were processed using an Arduino Nano microcontroller, which mapped the signals to predefined assistive commands using threshold-based logic.

The system uses fundamental preprocessing methods, such as noise filtering and signal stabilization for EEG inputs, as well as calibration procedures for gesture sensors, to guarantee precise signal interpretation. This enhances the reliability of command generation and reduces the number of false triggers. Additionally, the application of threshold-based logic reduces computational complexity, resulting in an efficient system for real-time embedded implementation without the need for significant processing power.

An input selection mechanism is provided to switch between the EEG and gesture modes based on user capability. The generated commands were displayed on a 16×2 LCD and converted into voice output using a DF Mini MP3 module. Figures 4 and 5 show the caretaker and transmitter sides, respectively.

By allowing users to select the method of interaction that best suits their physical condition, this dual-mode operation increases the flexibility of the system. Usability is significantly enhanced by the addition of audio feedback, particularly for users with visual impairments, as it guarantees immediate and clear communication. By focusing on simplicity and user-friendliness, the interface design minimizes the learning curve for new users.

For the remote alert functionality, the commands were transmitted wirelessly using a 433 MHz RF module to a receiver unit, where a buzzer was activated. The proposed system improves reliability by combining multiple input methods and ensures real-time operation with low-cost and low-energy consumption. The design is compact, portable, and suitable for assistive applications in home and healthcare settings. The experimental validation of the system shows that it performs consistently with low latency and stable wireless communication over practical distances. The modular design facilitates future upgrades, including the incorporation of machine learning algorithms for adaptive control, Internet of Things (IoT)-based remote monitoring, and mobile application interfaces. These improvements can further enhance the system's abilities, facilitating the development of assistive solutions that are more intelligent and tailored to individual needs, greatly enhancing the quality of life of people with disabilities.

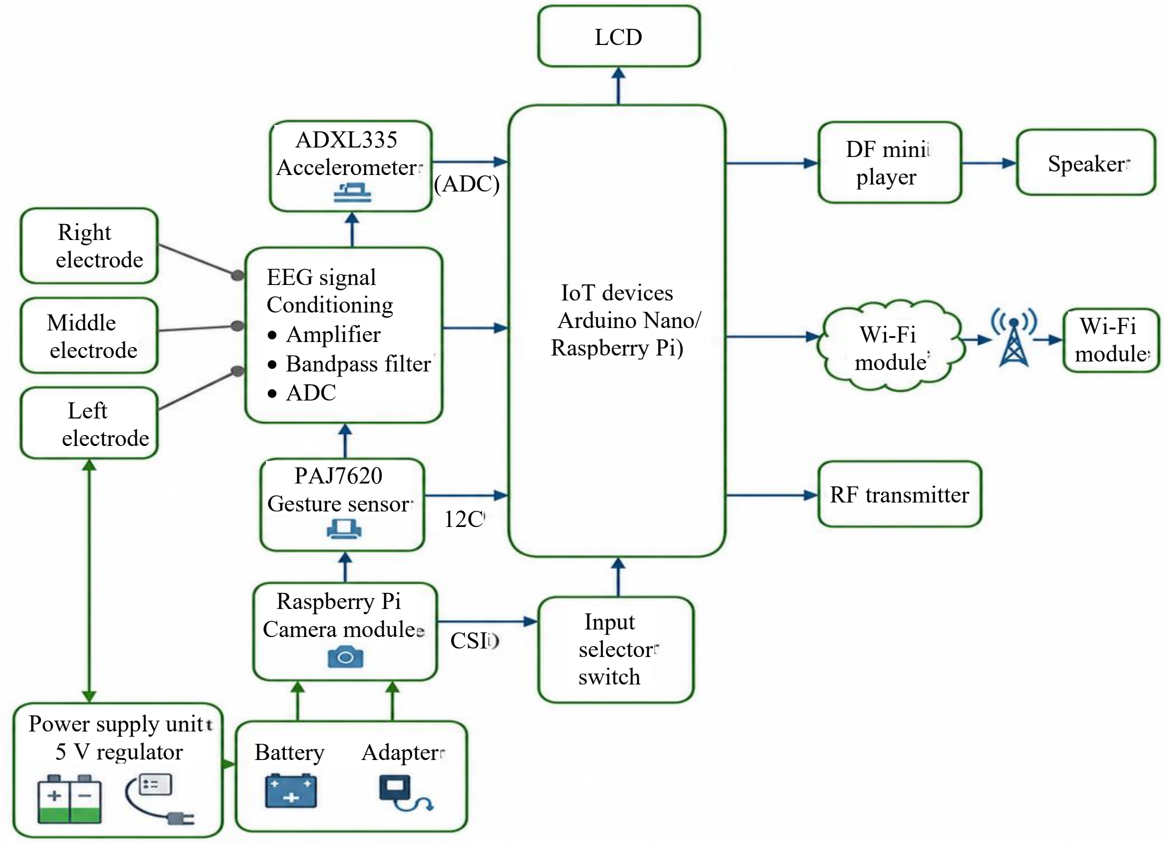

Figure 4. Transmitter side.

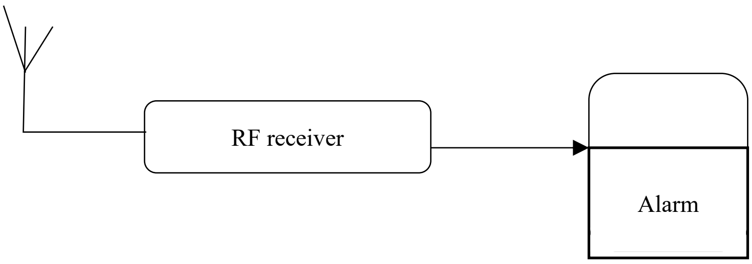

Figure 5. Caretaker side.

With the swift advancement of assistive technologies, the demand for systems that are both precise and adaptable to varying levels of user ability is increasing. Numerous existing solutions depend largely on one type of interaction, which may restrict usability for those with complex or multiple disabilities. The proposed system overcomes these limitations and improves accessibility for a broader user base by incorporating multimodal input. Furthermore, by emphasizing low-cost components, the technology remains affordable and accessible, especially in environments with limited resources.

METHODOLOGY

The system operates in two modes: EEG-based and gesture-based control. In the EEG mode, brain signals are acquired using electrodes, amplified, filtered, and converted into digital form using a microcontroller. A threshold-based method was used to detect intentional signals and generate commands.

In gesture mode, the PAJ7620 sensor detects predefined hand gestures using infrared sensing, whereas the accelerometer detects motion and tilt. The signals were processed and validated to avoid false triggering.

The microcontroller maps the detected input to predefined commands. The system follows a sequence of signal acquisition, processing, validation, and command execution steps. This ensures efficient operation and minimal delays.

SOFTWARE IMPLEMENTATION

The software implementation of the proposed system was developed using embedded C programming in the Arduino IDE environment. The program was designed to handle signal acquisition, processing, and output generation in real time.

In the EEG mode, the analog signal from the EEG sensor was continuously read through the microcontroller's ADC. A threshold-based algorithm was implemented to detect intentional brain activity, such as eye blinks or signal variations, and convert them into control commands. In gesture mode, the PAJ7620 sensor communicated with the microcontroller using the I²C protocol. The detected gesture codes were processed and validated using conditional statements to ensure accurate recognition and avoid false triggering. Accelerometer data were also analyzed to support motion-based inputs. The software maps the processed inputs to predefined commands, which are then executed by triggering the LCD, MP3 module, and RF transmitter. Interrupt and delay optimization techniques were used to ensure minimal response time and smooth system operation. The program is structured in a modular manner, allowing easy debugging, scalability, and future integration of advanced features, such as machine learning and IoT connectivity.

HARDWARE IMPLEMENTATION

The hardware implementation was based on an Arduino Nano microcontroller, as shown in Figure 6. The EEG sensor was connected to an analog input for signal acquisition. The PAJ7620 gesture sensor is interfaced through I²C communication, and the ADXL335 accelerometer is connected to the analog inputs. A 16×2 LCD was used to display the system status, and a DF Mini MP3 module provided audio output. Wireless communication was achieved using a 433 MHz RF transmitter and receiver, along with encoder and decoder circuits. All the components were powered using a regulated DC supply. Proper grounding and signal conditioning were implemented to ensure stable performance, as shown in Figure 7.

RESULTS AND DISCUSSION

The system was tested under laboratory conditions to evaluate its performance in this study. In the EEG mode, the system generated commands with an average response time of approximately 0.8 s. Signal noise was observed owing to electrode placement and environmental interference but was minimized through filtering.

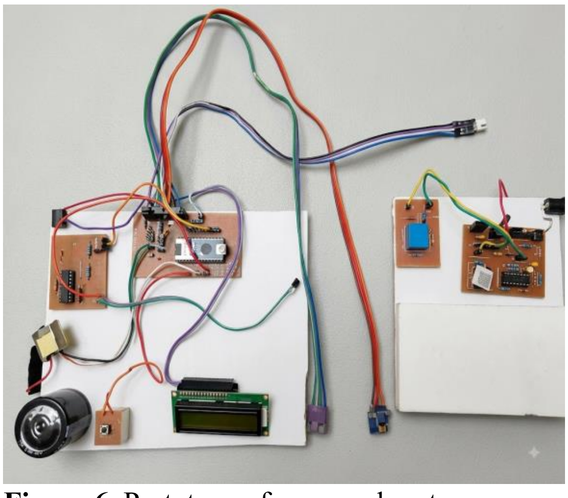

Figure 6. Prototype of proposed system.

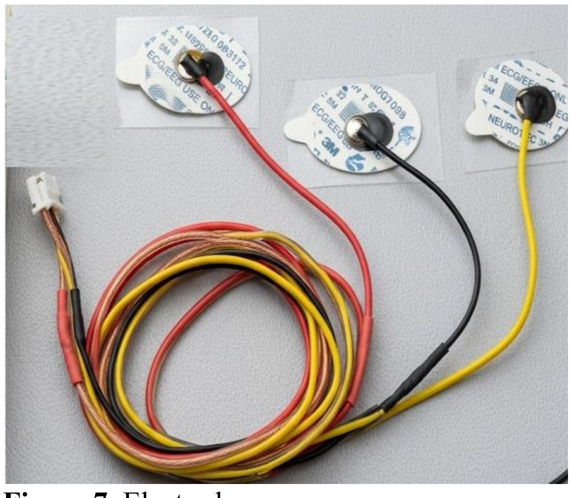

Figure 7. Electrode.

In gesture mode, the system achieved an accuracy of over 90% in detecting the predefined gestures. The response time was within one second, ensuring real-time operation. Wireless communication tests confirmed reliable signal transmission up to 20 m indoors. The integration of EEG and gesture control improved the reliability of the system by providing alternative input methods. The system performs better than single-input systems by providing improved flexibility and usability. However, EEG signals are sensitive to noise, and gesture detection can be affected by environmental conditions.

CONCLUSION

The proposed system demonstrates a low-cost multimodal assistive communication solution that uses EEG and gesture-based control. The system provides real-time response, reliable communication, and improved usability for individuals with disabilities. Incorporating advanced sensing methods guarantees a precise understanding of the user's intent. This reduces errors and improves the overall responsiveness of the system. This plays a major role in enhancing user interaction and minimizing communication obstacles in daily life. The integration of multiple input methods enhances the flexibility of the system and reduces its dependency on a single control mechanism. The modular hardware design and straightforward architecture of the system facilitate its implementation, maintenance, and upgrades tailored to user-specific needs. This flexibility accommodates various assistive situations and user needs. The proposed system is compact, energy-efficient, and suitable for practical assistive applications. Future improvements may include machine learning-based signal processing, advanced filtering techniques, and IoT integration for remote monitoring. By integrating cloud connectivity and real-time data analytics, continuous system optimization and remote assistance can be achieved, laying the groundwork for more intelligent and personalized assistive communication solutions in the future.

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